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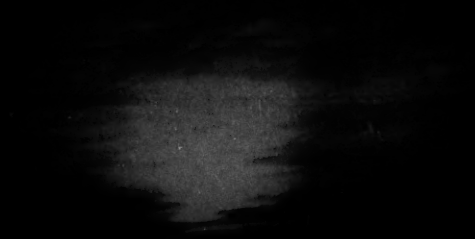

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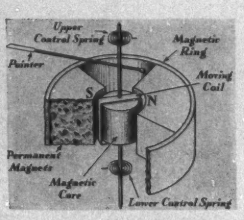

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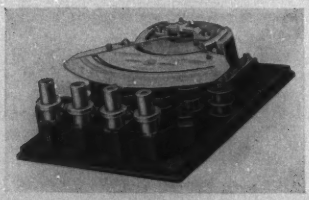

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Electrical Engineering

Registered U. S. Patent Office

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The Cover

On the 132-kv system of the Ohio Power Company near Shelby

Ohio Brass Company Photo

High Lights

New Telephone Instruments. Two papers in this issue describe new telephone instruments, which were introduced into service on the Bell System in 1937. One paper (*Transactions pages 559–64*) describes the instruments themselves, their design, and some of the structural characteristics; the other outlines transmission characteristics of telephone instruments in general, and shows how performance has been improved in the new instrument (*Transactions pages 606–12*).

Speed Control. Combination of thyratron control of motors with a tachometer whose output is used to control the motor input makes possible a small motor whose speed may be held constant under difficult conditions or varied rapidly in exact accordance with requirements. Applications are found in null-type high-speed recorders, high-speed controllers, and a motor-generator set synchronized with a constant-frequency low-power source (*Transactions pages 565–8*).

Oil-Impregnated Paper. Results of life-test studies on miniature cable specimens may contribute much to existing knowledge of power-cable failures. A paper in this issue, third in a series, attempts to show that with either paper of high density or an impregnant of high viscosity the flow of impregnant through the paper during the cooling portion of the daily heat cycle is not great enough to prevent void formation, consequent ionization and breakdown (*Transactions pages 573–9*).

Phase Shifting. To control the direction of power flow in an interconnected system loop, which may be used in emergencies, a large phase-shifting transformer is used that, by a series-parallel arrangement, may feed as much as 20,000 kw in one direction, or 40,000 kw in the other by control of the shift of phase angle. Net phase-angle shifts for the two conditions are 28 degrees and 15 degrees, respectively (*Transactions pages 579–87*).

Weather Forecasting. Modern, scientific forecasting of weather depends on rapid electrical communication to enable short-range forecasts such as are required for airways; new studies indicate the possibility of forecasts being extended to nearly a week. Recently radio has been used to transmit data from "robot observers" in stratosphere balloons and on mountain summits (*pages 405–12*).

1937 Lamme Medalist. Robert E. Doherty, 1937 AIEE Lamme Medalist, is a man of broad, diversified interests—yet a man with but a single purpose. He ranks high as an engineer, as a teacher, and as an executive. The story of this interesting man is told by a former colleague (*pages 420–3*).

AIEE Southern District Meeting. Plans for the AIEE Southern District meeting, November 28–30, 1938, provide for a generous amount of recreation and relaxation in picturesque Miami, Fla., as well as carefully planned technical sessions (*page 425*).

Field Tests of Bushings. Maintenance of insulation in good condition on all parts of a power system is essential to dependable operation. Of particular importance are bushings and transformers, which are satisfactorily tested by means of a field test of power factor. The application of this method on an expansive electric system is described in this issue (*Transactions pages 589–96*).

IEC Committees Meet. Torquay, England, was the scene of the ninth plenary meeting of the International Electrotechnical Commission, June 22–July 1, 1938. A new IEC committee on welding was formed, an international dictionary of electrical terms was approved for publication, and most of the committees submitted reports or final agreements (*page 424*).

Telephone Routes. Recent new construction has increased to four the number of transcontinental telephone routes. Some structural details have been modified in the new lines in order to take advantage of recently developed carrier systems operating at frequencies higher than formerly used (*pages 418–19*).

Supervisory Control. Selection time in large multistation supervisory-control systems may be reduced by eliminating the checking operation. A self-checking system has been developed that is based on the use of short or long electrical pulses, and is applicable to telephone lines or carrier-current channels (*Transactions pages 600–5*).

Lightning Protection. A decrease of 86 per cent in the index representing station-equipment faults in per cent of total system faults has been shown in the operating records of one power company following coordination of insulation and lightning-arrester performance in 22-kv substations (*Transactions pages 568–72*).

NRC Subcommittee Meets. Milwaukee, Wis., was the scene of the third successive joint meeting of the subcommittee on chemistry of the committee on insulation of the National Research Council and the American Chemical Society (*pages 426–7*).

1939 World's Fairs. Electricity will play a practically indispensable role in the World's Fairs to be staged next year in New York, N. Y., and San Francisco, Calif. Monuments to engineering achievement, the expositions will hold much of interest to electrical engineers (*pages 428–29*).

Labor Policy and Employment. Unemployment during the recovery period 1933–37 was primarily in industries that had not made sufficient technological advance, in the opinion of one economist (*pages 413–17*).

Coming Soon. Among special articles and technical papers now undergoing preparation for early publication are: an article discussing the objectives of industry in training engineering graduates, by L. W. W. Morrow (F'25); a paper on the design of harmonic generators, by F. E. Terman (M'34); two papers on air circuit breakers—one describing breakers for a-c feeder, motor starting, and station auxiliary service, by R. C. Dickinson (A'37) and the other describing low-voltage apparatus of high interrupting capacity, by Jerome Sandin (A'38); a paper describing an electronic position regulator for paper slitters, by F. H. Gulliksen(M'35); a paper on a static constant-current circuit, by C. M. Summers (A'30); a paper discussing some of the radio influence characteristics of electrical apparatus, by P. L. Bellaschi (A'34) and C. V. Aggers; a report of the lightning arrester subcommittee of the AIEE committee on protective devices, presenting performance data on lightning arresters of the line type; a paper describing a "memory attachment" for oscilloscopes, by W. E. Pakala (A'38); a paper on the electric strain gauge, by M. A. Rusher (A'12) and A. V. Mershon; and a paper on noise coordination of rural power and telephone systems, by H. W. Wahlquist (M'36) and T. A. Taylor (M'36).

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Progress in Weather Forecasting

By WILLIS RAY GREGG

Electricity and weather conditions are associated in two ways: electrical apparatus and structures are subject to damage by storms; and communication by telegraph, telephone, teletype, and radio is essential for weather forecasting. How the United States Weather Bureau has made increasing use of the information gathered from many stations for scientific forecasting, particularly for special services such as that for airways, is described in this article.

MAJOR storms and disasters, such as floods and hurricanes, may affect in a vital way electrical services, both power and communication. Before taking up the general subject of forecasting, however, it is proper to point out that, without the aid and achievements of the electrical engineer, meteorological service as it is known today would be utterly impossible. Dependence would still be placed on the astrologer, on the goosebone, rheumatic joints, saints' days, the ground hog, almanacs of various kinds, and so forth. It is interesting to recall that organized meteorological observations were not unknown to antiquity; in fact, Aristotle received reports from several hundred stations and wrote the first known treatise on the subject, but the reports were received by messenger; therefore, too late for current use.

Communication by Telegraph, Telephone, and Teletype

Down through the centuries other attempts were made to do something about the weather, not merely to talk about it, but it was only when electric communication was provided that anything really worth-while could be done about it. Significantly, within five years of the date, 1844, when the telegraph first came into public use, it was employed by the Smithsonian Institution in collecting weather reports for the purpose of forecasting storms. Its utility and value in this connection were quickly sensed by other countries. In November, 1854, a violent storm wrought havoc among the French and British warships in the Black Sea and sank many vessels containing invaluable stores intended for the allied armies in the Crimea. The French astronomer, Le Verrier, director of the observatory of Paris, collected information showing the progress of this storm across Europe, and the results of this inquiry were so significant that he sub-

Essentially full text of an address delivered at the AIEE summer convention, Washington, D. C., June 20–24, 1938.

WILLIS RAY GREGG was chief of the United States Weather Bureau, Washington, D. C., from 1934 until his death September 14, 1938. A graduate of Cornell University in the class of 1903, he was with the Weather Bureau continuously from 1904, and since 1926 had been engaged in organizing weather service for commercial airways activities. He was chairman of the executive committee of the National Advisory Committee for Aeronautics, and a member of several technical societies.

The author was indebted to Doctor Horace R. Byers of the Weather Bureau for helpful suggestions in the preparation of the sections on "Physical Basis of Forecasting" and "Research."

Diamond-type radiometeorograph, showing mechanism for recording pressure, temperature, and humidity

mitted to the Emperor Napoleon III the plan of organizing an international system of telegraphic reports, by means of which timely warning could be obtained of similar atmospheric disturbances. The French government, with the aid of other European countries, established such a system in 1855. Within the next two decades most of these countries organized their own services, and at the same time maintained an international exchange of observations by telegraph. Service in the United States was officially authorized in 1870. Thus within a generation of the time when the telegraph became available as a means of communication, practically all civilized nations were making use of it in providing daily forecasts and warnings for their people.

Later came the telephone which supplemented the telegraph in a most effective way, both in the collection of reports and particularly in the dissemination of meteorological information, including forecasts and warnings, to millions of people requiring such service. The fact that more than 8,000 telephone calls were received and answered at the Weather Bureau office of one large city, in the short space of 24 hours, during a flood emergency, indicates the tremendous importance of this means of communication in performing the functions of a meteorological service.

Then there is the teletype which provides an almost instantaneous exchange of reports at frequent intervals along more than 21,000 miles of airways and, during the hurricane season, connects many reporting stations along the Gulf of Mexico and south Atlantic coasts. It is destined to be still further extended, eventually combining into one system the entire network of meteorological stations in this country and probably in others.

Radio Communication

It is not too much to say that the introduction and widespread use of radio marked the beginning of an epoch comparable only to that initiated by the telegraph. It has extended the meteorological horizon to the seas and to remote and isolated regions of the continents. The first weather report from a ship in the Atlantic was received December 3, 1905; in the Pacific, June 18, 1907; and in the Caribbean, August 26, 1909. In 1906 the total number of marine reports received was 738; in 1922, 1,500; in 1933, 56,800; and in 1937, 89,165.

The record as regards land reports is no less noteworthy. International exchanges were begun in 1921, and at the present time twice-daily bulletins are received from Rugby and Cavite as well as individual reports from many other points, including several stations in northern Siberia, northern Canada, and Greenland. The isles of the Pacific and of the Caribbean add their quota to this ever increasing volume of data, with the result that twice-daily weather maps of the entire Northern Hemisphere now are made and the time is not far distant when such maps for the whole world will be available.

So much for radio as a collector of reports; its role as a disseminator is equally impressive. Naval radio broadcasts were begun in 1904. All marine interests now receive forecasts and warnings in this way. Radiophone broadcasts in the United States were begun in 1921, the first one being by the University of Wisconsin on January 3, 1921. The first flood warnings were broadcast by the University of Missouri on April 26 of the same year. At present there are 435 radiophone stations regularly broadcasting forecasts and warnings for the benefit of the farmer, the merchant, the shipper, the orchardist, the housekeeper, the baseball fan, the motorist, and the golfer. Radio not only guides the aircraft pilot on his way but keeps him constantly informed of current weather ahead of him and of impending changes. In short, it is difficult to visualize a meteorological service without radio as a chief factor. Yet, with all that it is and does, undoubtedly only a beginning in taking advantage of its possibilities has been made. Already complete weather maps are being transmitted to ships at sea. This service is in the experimental stage at present, but will certainly be extended and will include ships in the air and distant land stations also. But the most far reaching development, now rapidly passing out of the experimental phase, is that wherein radio plays the role of a meteorological observer as well as that of a transmitter of the data. This refers to the apparatus that is variously known as the radiosonde, radio telemeter, or, generally up to the present time in the United States, as the radiometeorograph.

Significance of the Radiometeorograph in Meteorological Service

Space does not permit more than a brief statement regarding the design of this instrument. It consists essentially of a radio transmitter which is actuated by a barometer, a thermometer, and a hygrometer, all of extremely light weight but high precision. Four principles of operation have been employed. The most widely used is the Olland system of telemetering (a simple form of television) in which an attempt is made to telemeter the position of the index of the meteorological element relative to a time scale. The next in order of general use is one in which the meteorological elements vary the capacities

of the radio-frequency oscillator, thereby varying the carrier frequency. Another principle of operation is to key the carrier by means of the meteorological elements, thus causing a sequence of coded signals to be transmitted. Finally, there has been employed an audio oscillator whereby the carrier frequency is modulated and produces variations in modulation by changes in resistances that are varied by the meteorological elements.

Each of these designs has certain advantages and disadvantages. It is too early as yet to say definitely which one ultimately will prove to be the most efficient, but all have been brought to a point already where they give reasonably reliable data. During the present fiscal year different designs have been used by the Weather Bureau at three places and the present plan is to extend the program to include six stations. The experience of this coming year and the improvements resulting from that experience will, it is believed, make possible the adoption of one design, or possibly a combination of the best features of two or more, as the most efficient, and to substitute this method of upper air exploration for others heretofore employed, so far as pressure, temperature, and humidity are concerned. There remains the problem of adapting this apparatus to include measurements of air movement. This is difficult but it is being attacked and there is good reason to expect that it will be solved.

The regular use of the radiometeorograph will unquestionably mark the beginning of a new epoch in meteorological service. Attached to a balloon, it will ascend to heights of from 10 to 20 miles, therefore well up into the stratosphere. It will secure data in all conditions of weather, thus overcoming a serious handicap to which all other methods are subject. Finally, it will give those data immediately while the balloon is ascending instead of two or three or more hours after the sounding is completed.

Nor will the benefits be limited to knowledge of the upper air. These instruments, or apparatus based on the same principle, can be placed on small islands—for example, in the West Indies and Caribbean Sea—to give data of inestimable value during the hurricane season. The same use can be made of the apparatus on islands in regions which are subject to destruction by typhoons.

It is generally recognized that great benefit will result from more detailed information regarding conditions in the polar regions. Such information will be secured through the organization of a network of stations in regions where man does not live. It will be perfectly feasible to install the equipment which will transmit the data as frequently as desired, and which can be kept functioning through only very rare inspection visits by means of an airplane.

Again, much thought is being given at present by practically all meteorological services to the desirability of taking up mountain observatory work more actively than ever before. The great difficulty is that establishing observatories on very high summits involves many problems and large cost. The radiometeorograph will solve this problem also, and at comparatively small expense.

The possibilities for the use of the principle of the radiometeorograph or the "robot observer" are, in fact, almost endless and abundantly justify all the feverish activity that is now in evidence in many countries in bringing the equipment to a point where it can be used in regular service.

Present Trends in the Development of Meteorological Service

The subject of communications, particularly radio has been treated at some length partly because it seems appropriate to pay tribute to the electrical engineering profession for its contribution to meteorological service and partly because the rapid development of communication facilities makes possible a corresponding extension of the observational field, both in the horizontal and in the vertical. Hand in hand with these advances have come improvements in instrumental design, in the training of personnel and in international standardization of codes, units, symbols, and definitions, with the result that data from all sources are becoming progressively more accurate and are directly comparable, in addition to being promptly transmitted. Thus, meteorological services are being provided with the working tools that are essential for the development of those services in line with two chief present-day trends which are:

First, the application of sound physical laws to forecasting, displacing empirical methods on which until recently, owing to lack of sufficient data, dependence was necessarily placed.

Second, the organization of a more detailed and intensive type of service to meet the specific needs of individual interests and activities than has heretofore been provided.

Physical Basis of Forecasting

As has been mentioned already, attempts to use simultaneous reports from a network of stations as a basis for forecasting were made very shortly after the telegraph became available, but it was not until about 1870 that official meteorological services were organized by the various governments. Since that time chief dependence has

Observatory on Mount Washington, N. H., 6,290 feet above sea level

been placed on the well-known synoptic map, which shows the geographic distribution of the meteorological elements and their changes from day to day. It is well known that weather conditions travel in a fairly regular manner, altering more or less as they move, and it is possible, from a detailed study of past synoptic charts, to estimate from a current map the changes that will take place during the next day or two in the location of cyclones or "lows" (regions of relatively low pressure) and anticyclones or "highs" (regions of relatively high pressure) and in the accompanying weather conditions that are characteristic of these pressure formations. Much progress was made during the early years of use of this method, but, being empirical, a "dead line" of dependability was presently reached beyond which further improvement is not attainable.

During this early pioneer period many theoretical investigations clearly established the fact that it is not the cyclones and anticyclones as such that are important in determining weather, but rather the interactions between the various air masses that go to make up those systems of high and low barometric pressure. These air masses from different source regions, polar, equatorial, continental, and marine, have distinct characteristics of temperature, humidity, and movement, and they tend to maintain their individual identities over comparatively long periods of time, with the result that at their surfaces of contact they form more or less marked discontinuities or "fronts." It is along these frontal surfaces that the processes involved in weather phenomena are most active, and the study of them, now generally referred to as "air mass analysis," already has proved itself a powerful aid in developing forecasting along sound physical lines.

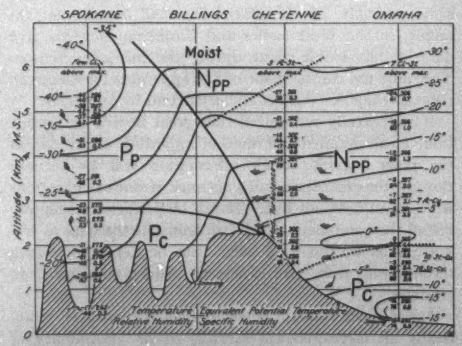
The introduction of a new technique, especially when it involves the use of data of a type not previously available, requires careful study to determine the most effective means of presenting those data for rapid and thorough analysis. The "raw" observational material is useful in showing the current state of the individual meteorological elements, but offers little aid in an understanding of the energy transformations that are taking place. For this latter purpose various so-called "energy diagrams" have been devised which bring out clearly the more prominent characteristics of the air masses that are present and give a picture of the structure of the atmosphere as regards its temperature, humidity, and other conditions.

Adiabatic Charts

The adiabatic chart is the fundamental diagram for plotting the data from individual ascents. The sounding is plotted with temperature as abscissa, and pressure on a logarithmic or exponential scale as ordinate which is approximately equivalent to a linear altitude scale. On the diagram may be located the various temperature inversions (atmospheric strata in which the temperature increases instead of decreases with height) which are significant as marking the tops of turbulent and convectively-stirred regions and which also coincide with the tops of haze, smoke, and cloud layers. Furthermore, these temperature inversions, especially if accompanied by inversions in the vertical distribution of moisture, may signify the presence of frontal surfaces. Adaptations of the adiabatic chart have been devised, from which the energy realizable for vertical convection can be determined—one of the few precise physical computations that can readily be applied to forecasting and which is of great value in forecasting local showers and thunderstorms. The procedure consists in following the changes that would occur were an isolated element of surface air forced to move upward along an adiabatic line, and comparing its temperature, and therefore its density, at each level with that of the surrounding atmosphere through which the element is forced to rise; the conditions in the surrounding medium are given by the data of the airplane observation. If the isolated rising air finds itself in an environment that has a lower temperature, then it will not be in stable equilibrium and will be accelerated upward, thus being capable of producing the strong ascending currents necessary for the formation of thunderstorms. In its ascent the air, after reaching the condensation level of its water vapor, cools at the so-called saturation or pseudo-adiabatic rate, which is less rapid than the adiabatic cooling rate before condensation because of the gradual release of the latent heat of vaporization in the cloud. A convective-energy diagram called an "emagram," based on the adiabatic chart, with temperature as abscissa and pressure as ordinate, is highly useful, since it shows, by its so-called "positive area," the amount of energy that is available for convection.

Vertical Sections

Another valuable form in which the upper air conditions can be quickly visualized is by means of the so-called "vertical section" which shows observed and equivalent potential temperatures, relative and specific humidities, winds, clouds, and so forth, as ordinates and a geographic



Vertical section for Spokane-Omaha on February 13, 1936, showing inflow of polar Pacific air aloft as cold front over polar continental air

Cold front shown by heavy solid lines, warm front by dotted lines, and isotherms by light solid lines. The meaning of the figures grouped around the marked positions on the vertical lines is shown by the model at the bottom of the diagram

section of the country, west to east, north to south, or any other direction, as abscissa. Necessarily the vertical scale is greatly exaggerated. Several such vertical sections are required to show the conditions for the entire country. As yet a method has not been devised that would combine all into one chart, nor is it likely that it ever will be. However, a study of these vertical sections, together with the surface weather map, enables one to form a fairly comprehensive picture of the distribution, both horizontal and vertical, of the various air masses and of the surfaces of discontinuity separating them.

Isentropic Charts

One of the most recent and most promising advances in charting the upper air is the development of the so-called isentropic chart. This method is based on the fact that in the free atmosphere, most movements are along adiabatic or isentropic surfaces, that is, surfaces of constant potential temperature; potential temperature is defined as the temperature attained in an adiabatic reduction of pressure to 1,000 millibars (one million dynes per square centimeter). Instead of drawing charts of the air currents on level surfaces, or surfaces of constant height, the circulation is charted along the isentropic surfaces, which normally are sloping surfaces, and thus the currents are followed along the surfaces on which they actually move. The paths of the air currents can be traced by following the course of "tongues" of water-vapor maxima that appear on the charts. These moist tongues, especially where they are carried in currents moving rapidly upward along the isentropic slope, are correlated with areas of precipitation and cloudiness. In forecasting the behavior of these tongues, one can arrive at a very good idea of the future course or development of precipitation areas. A study of these charts has shown that the atmospheric circulation tends to break up into much smaller eddies than was previously supposed to be the case. New theories of the general circulation of the atmosphere are being developed from these findings.

Practical Results

Now the question naturally arises, what are the practical results thus far achieved? In answering this question one must bear in mind that two or three years constitute a very short period, and one should not be discouraged if the results are no more than suggestive of what may be expected from further use of any new method. Happily, however, in the present case there are some results that are not merely suggestive as to the future but which show definite improvement along some lines already.

It was early recognized that air mass analysis would find its most effective application in the short-period forecasts such as are required for the safe and efficient operation of activities along the airways. Within a year after the introduction of frontal analysis in the Weather Bureau the practice was adopted of transmitting over the airway teletype system information as to the location of fronts, and these have been placed on the weather maps that are prepared several times daily at all airport stations. It is well known that material improvement has resulted in the general character and accuracy of this type of forecast, as is abundantly attested not only by officials of the bureau, but also by the recipients and users of the forecasts themselves.

Can as much be said in the case of the longer period, that is, the regular 24- to 36-hour forecast? Not to the same extent as yet, but there are certain definite results already and they are all in the right direction. They show that the original plan to integrate the analyses and their applications to forecasting with the already existing forecast procedure and with the accumulated knowledge and experience in the past has, even in the short period thus far devoted to its development, made considerable progress in the forecast service at the central office in Washington. For more than a year now the intermediate weather maps that have been analyzed in detail by the trained personnel of the air-mass section have been furnished as a guide for quick and reliable analysis on the principal morning and evening maps by the forecasters. The forecasters report that "this helps materially in readily locating the fronts and identifying the different air masses on these maps. Therefore, the forecasts are always expedited and at times are issued with more confidence because of greater assurance of a correct analysis of the current map."

With wholly inadequate funds for research, with not even enough for the barest needs of current service, for that matter, progress necessarily is slow but it is positive, to a degree that has justified an extension of the program to field stations. A beginning along this line was made several months ago, through the detail of an official in the air-mass-analysis section to important forecasting centers in the airway service. In the meantime several young men who have received special training at the central office and have returned to field assignments are passing on to others some of the knowledge they have gained.

Specialization in Forecasting

All of this leads naturally to a consideration of the second chief trend in the development of modern meteorology, namely, providing a more detailed and intensive type of service, including forecasts, to meet the ever increasing demands incident to the initiation of new activities, or the expansion of already existing activities, in our present complex social and economic structure. Until comparatively recent times a generalized type of service was accepted as reasonably satisfactory or, at any rate, as the best that could be had. No one thought very much about a more detailed service. All this is now completely changed. Every activity that is more or less affected by weather; in agriculture, commerce, marine and aerial navigation, demands and, in increasing measure, is receiving a specialized and intensive type rather than the more generalized type of a few years ago. At that time and during the half century preceding it the official of a Weather Bureau station provided service for all types of activities. He was, so to speak, a "Jack of all trades" and, therefore, through no fault of his own, "master of none." Now, on the other hand, specialists are employed

who have had intensive training in a particular branch of the service and devote all of their attention to it. This change is wholly in harmony with the spirit of our own time which, as is well known, is one of specialization to a greater degree than has been any previous age. In conforming to this fundamental change, practically all branches of the bureau's service have been very materially modified and, it is believed, definitely improved. A few examples may be of interest.

Airway Service

Undoubtedly the greatest impetus to the organization of specialized service was given by aviation. For this activity it was found necessary, in fact vital, that weather reports be available at more frequent intervals and from a larger number of places, both along and off the airways. Certain weather elements not previously measured were essential, such as visibility and ceiling, or height of the lowest cloud layers. Moreover, the general daily forecasts were quite inadequate to meet this new demand. They must be much more detailed and specific and cover a shorter period corresponding approximately to that of the flight itself, namely, from three to five or six hours.

At the same time it was found that certain other aids, such as intermediate landing fields, beacon lights, and prompt communication facilities were required both for safety and for efficiency. A growing recognition of these needs culminated in the adoption on May 20, 1926, of what is known as The Air Commerce Act which authorized the Department of Commerce to provide all necessary navigational and other aids except weather service, this last duty being naturally assigned to the Weather Bureau.

During the 12 years since the passage of this act weather service for aeronautics has undergone a profound evolutionary development, being today specialized to a degree that would have been regarded as wholly fantastic and unwarranted a quarter of a century ago. There are at present some 33,000 miles of civil airways, including those in Alaska and the Hawaiian Islands, and about two-thirds of these on which flying is more or less continuous are provided by the Department of Commerce with 24-hour teletype service. Along these 21,000 miles of airways hourly weather reports are regularly transmitted from stations so located as to provide a complete picture of current conditions and of changes from hour to hour. Intermediate observations also are made when marked changes occur. On airways which are as yet less active and therefore are not provided with teletype service, observations ordinarily are made less frequently, but nevertheless at such intervals as to insure covering adequately all regular scheduled flights.

In addition to these reports from points on the airways others are received every six hours from well located off-airway stations. Two of these collections include data from the bureau's primary or basic system of reports from all first-order stations, from Canada, Alaska, Mexico, the West Indies, and from the oceans.

Of great importance are the measurements of upper air conditions by pilot balloons and airplanes, and, more recently, as previously stated, by radiometeorographs.

Official photograph of U. S. Navy

Airplane with aerograph (mounted on wing) which records weather observations automatically. Observations of this type are made daily under contract with commercial pilots and through co-operation with the Navy Department at a number of points throughout the country. One of the requirements is that the plane must reach an altitude of at least 17,000 feet

Additional information regarding conditions aloft is obtained from observations of clouds, particularly the heights of their bases as determined with small so-called ceiling balloons in the daytime and with ceiling lights at night. Then too there are the reports from mountain stations and from pilots flying along the airways.

All in all, the airway service embraces nearly 800 stations of various types, some providing reports only of surface conditions, others including upper air data also and still others adding to these functions that of maintaining direct contact with pilots and officials of the air transport companies themselves. Of this last type there are now more than 50 stations at the larger terminal and many intermediate airports, where weather maps are made and pilots and others kept advised of conditions in all parts of the country in which they are interested, this service being on a 24-hour basis throughout the year. Eleven of these airport stations are district forecast centers, where personnel of proved technical ability in forecasting also provide continuous service, issuing four times daily forecasts for the next eight hours, with supplementary warnings in cases in which conditions are rapidly changing and differ from the prediction previously made. These forecasts not only are given to those interested locally, but are widely distributed, along with the reports of current conditions, by the Department of Commerce communication system which includes, in addition to teletype, an extensive network of radio stations, thus enabling pilots in flight to be kept constantly informed of current conditions along all parts of their routes and of predicted changes. The forecasts are expressed in very definite terms, with special emphasis being given to ceiling, visibility, line squalls, ice formation, and any other conditions that present a real hazard. They indicate also the upper wind conditions, thus enabling pilots to select an altitude where the flight can be made with the greatest possible speed consistent with safety. As earlier stated, the techniques developed in air mass analysis work have contributed very effectively in improving this branch of the bureau's work.

Such in brief are the main features of the airway meteorological service as it functions at the present time. Only an extreme optimist would claim that it is ideal. It is only about ten years old. During this period there has been much experimentation, with changes and improvements resulting as suggested by experience. There is reason to believe that the basic and essential features are sound and will probably endure, but there are bound to be further improvements as new ideas and methods are proposed and introduced. The Weather Bureau is now actively engaging in many research projects, all designed to bring about such improvements.

Hydrologic Service

Although river and flood forecasts have been issued since 1871, it is only recently that this problem has been attacked with due regard to the engineering phase. This has come about partly because of the series of floods that have brought disaster to many parts of the country and partly because of legislation authorizing a comprehensive program of flood control.

Flood forecasting utilizes two methods which differ markedly in principle. On the larger rivers and on the lower reaches of the smaller streams gauge relations are sufficiently consistent to permit an accurate estimate of expected stage far enough in advance to make adequate preparation for evacuation of areas doomed to inundation. Forecasts are developed progressively downstream, properly adjusted to increase in flow from important tributaries. The period covered by the forecasts ranges from two or three days in the upper valleys to as much as three or four weeks in the lower Mississippi Basin.

As the headwaters are approached, however, prediction of river stage becomes increasingly complicated. The amount and rate of the rainfall, the slope of the land and the stream channel, the character of the watershed and its cover, and the influence of antecedent rainfall—factors which have been integrated into terms of stage on the lower river—now become variables which must be dealt with separately and quantitatively.

This nation is rapidly becoming flood conscious, with the result that the Weather Bureau has been forced to extend its river forecasting service into the headwater areas of nearly all the principal streams. There has been neither time nor opportunity to prepare for basic changes which involve method and procedure wholly without precedent. At many important up-river stations, the forecaster has only a comparatively few hours to foretell the approach of a flood and that under the conditions of "flashy" stream flow typical of headwater tributaries. Pittsburgh is perhaps the best example of such a situation. Any plan to meet this problem must be prepared to predict flood stage practically as the rain falls and the snow melts. The city itself must be organized to evacuate certain areas with the precision of a fire department. Industry and business occupying danger zones must plan to waterproof against the rising water or to remove damageable goods to higher levels on minimum notice. This city, and other municipalities so situated, must maintain stand-by emergency water supplies and lighting facilities. Permanent concentration centers must be selected in advance and emergency housing provided. These and other plans in considerable detail are being formulated by the agencies charged with the responsibility of dealing with great floods.

The flood of January 1937 in the Ohio and lower Mississippi rivers illustrates the application of both approaches to the problem of flood forecasting. The forecasts for the Mississippi, for example, were almost entirely on the basis of upstream stages. Those for the Ohio on the other hand were based in considerable part on the occurrence of the heavy rain that prevailed for the greater part of the month, causing the upper river to crest 24 to 36 hours after the rain ceased.

In order to meet these rapidly increasing needs it has been necessary to reorganize the hydrologic branch of the service so as to bring about a much closer co-ordination with agencies in charge of flood-control programs and to permit greater participation in fundamental research. To this end the country has been divided into 12 hydrologic regions, 5 of which are now provided with regional offices and personnel. The regional offices are being manned by qualified hydrologic engineers who will gather data, develop methods of estimating stream flow, devise means of assembling flows, and co-ordinate and unify the forecasting program.

As rapidly as funds permit, the network of recording rain gauge stations is being extended. Increasing attention is being given to the accurate measurement of evaporation and special studies are being made to determine basic relationships between snowfall, snow-melt, temperature, ground-surface conditions, and runoff.

A research project which is believed to be of very real significance is one that is now being conducted co-operatively with the Corps of Engineers to estimate spillway and waterway capacities. The procedure is to make a detailed study of major storms that have resulted in excessive precipitation and floods, transpose these storms within reasonable limits to other locations with respect to nearby river basins, take other factors such as topography, snow cover, and a different temperature distribution into consideration, and endeavor to determine what is the maximum runoff that is ever likely to occur. This is a direct application of the work that is being done in air mass analysis, the isentropic chart, previously referred to, playing a prominent part. It is planned to extend this study to all of the principal river basins in the country.

Hurricane Warning Service

Another good example of present trends is the hurricane warning service which was materially strengthened three years ago. The main features are: (1) a 24-hour teletype service connecting points along the Gulf of Mexico and south Atlantic coasts, from Brownsville, Tex., through Key West to Jacksonville, Fla., thus providing for frequent exchange of reports and prompt transmission of forecasts; (2) an increase from two to four reports daily from ships in the Gulf of Mexico, West Indies, and Caribbean waters; (3) close co-operation with the Coast Guard; and (4) the assignment of specialists trained in

In the wake of a hurricane. Warnings issued by the Weather Bureau of the approach of these destructive storms are of inestimable value to shipping and many other interests

hurricane forecasting to New Orleans, Jacksonville, and San Juan.

Along with the development of this service there has been organized, co-operatively with Massachusetts Institute of Technology, a research project which consists in sending up recording apparatus, attached to balloons, during the passage of hurricanes, preferably as near their centers as possible. Only a few records thus far have been secured, but they show some interesting features regarding atmospheric structure in the upper portions of these storms. This investigation is being continued in the hope, not that hurricanes will occur but that, if they do occur, we shall obtain information that will increase our knowledge of their characteristics and thus enable us to forecast their formation and movements more accurately.

Research

Time does not permit consideration of many other examples of the present tendency to specialization of service. In all of them, as well as in those that we have discussed, research is playing an increasingly important role. A broad comprehensive research program is in fact fundamental to any future progress. The Weather Bureau is limited as to funds for the development of such a program, but fortunately the Bankhead-Jones Act for research in the Department of Agriculture makes possible a definite beginning along this line. Only brief mention can be made of a few of the more important of these projects. One of them is an investigation of the conditions which give rise to the building up of huge domes of polar air in Alaska, these later moving southward and developing into the cold waves that invade and spread over large sections of this country. Upper air soundings with airplanes and radiometeorographs, together with measurements of outgoing radiation, have been made at Fairbanks, Alaska, Fort Smith, Canada, and at points along the northern border. Already some significant conclusions have been reached, although it is too early to announce any definite results.

Attention is not being limited to winter conditions, however. Equally important, in some respects more important, because of their relation to agriculture, are studies now in progress to apply air mass analysis methods, and particularly the isentropic chart, to the forecasting of thunderstorms and precipitation generally during the summer season. The number and frequency of upper air soundings are not yet adequate for this investigation, but the results thus far nevertheless give a substantial basis for optimism that forecasting of summer rainfall, including thunderstorms, will be materially improved and that the period of the forecasts can be extended to something like five days, possibly longer.

An investigation of considerable promise has to do with solar variations as they may affect the atmospheric circulation, and special attention is now being given to the question of atmospheric ozone as a possible link between solar activity and changes in the circulation of the atmosphere. Measurements thus far made show that ozone is greatest in amount a short distance to the rear of low-pressure centers and least in the corresponding part of high-pressure areas. It would seem then to be a valid assumption that the variations in the amount of ozone are related not to the barometric pressure itself but rather to the sources of different air masses, the ozone being most abundant in polar and least in tropical air. There is thus the possibility of utilizing the measurements of ozone and its variations in forecasting the development and movement of the different types of weather that are associated with fronts, anticyclones, cyclones, etc.

Many other problems are being attacked in a very definite way, such as the conditions that produce ice formation on aircraft and widespread sleet and ice storms that cause so much damage to power lines. The hazard of lightning to aircraft is now receiving special attention. Nearly all of these investigations are being conducted co-operatively, in part with other government agencies, in part with educational institutions, and in part with interested individuals. Meteorological services of other countries are likewise active. It is in fact one of the hopeful signs of the times that research is assuming its proper place in the development of modern meteorology.

New Outlook

Attempt has been made to outline briefly some of the main features of the present program of reorganization of the Weather Bureau designed to bring about improvements in the service, including particularly forecasting. It may be noted that much of this relates to the future. Nevertheless, very real progress has been made in some lines already. The point of real significance is that a break definitely has been made away from an ultraconservative attitude, from dependence on old established methods, and the service is being developed in line with modern scientific thought and procedure. Encouraging results already are being realized; others are bound to come as the program is continued and extended.

Labor Policy and Employment

By LEO WOLMAN

Maladjustment brought about primarily by too speedy reform is cited by this noted economist as one of the principal causes of the present long-range trend toward increased unemployment. Speaking of various industries, he expresses the belief that unemployment persisted in certain industries during the recovery period ending in 1937 because those industries had not made sufficient technological advance.

WHEN examined as a long-term problem, unemployment everywhere in the world seems to be getting bigger; and that began right after the war. It is higher, of course, in the depression than it is in the subsequent recovery, but in the subsequent recovery it is higher than in the preceding recovery.

Now, that is a very important thing if true. I want to rule out some countries in considering this trend. I won't include Germany, Italy, and Russia, not because they have no unemployment but because we can't get the figures that we are able to get from other countries, notably England and the United States.

In these two countries unemployment seems to have moved something like this: Before the war the unemployment rate in England was about five per cent. During the war, of course, everybody was employed except the unemployables, and the unemployment rate descended to an unprecedented low level, and then after the war came the *depression*. From 1922 to 1930 the British had an unemployment rate of ten per cent. These are rough figures—I am quoting from memory—but they are close enough to the truth to be useful.

So in the *recovery* of business in England in the 1920's (I am ruling out the 1921 depression) the British unemployment rate was two times the prewar rate. During the depression of 1930 the unemployment rate shot up again to a great height, but I am not dealing with depression periods because everybody knows there is more unemployment in depression than in prosperity. So I go to the next prosperity period, which in England began in 1932, and which gave some indication of being on the verge of terminating October 1937. At any rate the unemployment rate began to go up in October 1937, and its spring recovery was not as great as spring recoveries have been before. But if you chart these turns, their curve turned in the fall of 1937. If you take their recovery years 1932 to 1937 and estimate the unemployment rate through that whole period, you will find that it runs about 13 to 14 per cent.

This is an extraordinarily important series of figures. A 5-per cent prewar unemployment rate, a 10-per cent postwar prosperity unemployment rate, and then a 13-per cent post-depression unemployment rate in the latest recovery of business. And the recovery of business was very healthy in England, where industries that had long been depressed, like textiles, iron and steel, and shipbuilding, had a great deal of activity and foreign trade prospered again.

Now, I want to discuss briefly what is meant by minimum unemployment rate. We know that it was once the rule that all or practically all of the unemployed were absorbed during the prosperity that followed depressions. But in England from 1920 to the present that does not seem to happen. Not only doesn't it happen at all that most of the unemployed are absorbed, but apparently, in other countries as well as England, during each recovery, the unemployment rates ascend to a plateau and stay there.

Trend in Unemployment Rate

I don't for a moment believe that this trend is going on without end, but what I am afraid of, and do almost believe, is that England and other countries, including the United States, will settle down to a relatively high unemployment rate of that kind, even during periods of prosperity.

Employment statistics in the United States historically aren't as good as the British, but we began to get them in the 1920's; we did better than England in the 1920's and we had a lower unemployment rate then. I want to talk about that in another connection later, but our interesting history begins in 1933 from this standpoint.

Beginning 1933 you will remember, we had signs of a business recovery and there were certain hesitations and certain turns in the business curve, but business activity continued to ascend until—authorities differ on this—the end of 1936 or beginning of 1937. The year 1937 as a whole was pretty good, and then the curve began to descend. So we had a period of about four years of prosperity and when you look at the unemployment figures, putting the best face on unemployment and the worst face on it, taking the figures of the National Industrial Conference Board on the one side and the American Federation of Labor on the other, we settled down in this period to a volume of unemployed of about seven million. Now, seven million gives a pretty high un-

Essential substance of an address presented at the first public forum held May 13, 1938, in Philadelphia, Pa., by American Engineering Council, on the subject "Employment and the Engineer's Relation to It."

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employment rate—say about 14 per cent. That is an unusually high rate for a period of prosperity.

Students of this problem began to come to the conclusion that we are probably in for that sort of thing for some little time to come. The great danger confronting countries like the United States and England is that in the period of recovery the unemployment rate will remain relatively much higher than formerly and possibly higher than it was during the last period of prosperity.

Anybody who is familiar with our ways of dealing with the unemployment problem directly knows that the persistence of a relatively high rate of unemployment is at the root of the most fundamental and troublesome of our economic problems today. To this problem of dealing with unemployment we can trace all our big national economic problems—unbalanced budget, heavy and expanding public expenditures, currency problems, credit and banking problems, problems of floating the national debt, the charges imposed on business by way of taxation to take care of expanding expenditures, and the whole series of questions like that.

Methods of Dealing With Unemployment

How do you deal with unemployment? There isn't any mystery about it. You don't have to be an economist. We have had a long history of dealing with unemployment, and I'd like first to mention the formal methods. There are three methods of dealing with the unemployment, barring economic planning. Economic planning is essentially, after all, only saying you would like to regularize business so you won't have unemployment. Economic planning is partly a statement of wish. Barring that approach to the question we have had several pretty well defined, simple ways of dealing with unemployment.

When the British Poor Laws Commission made its report in 1909, it agreed on three things that should be done: first, an increase in public works in time of depression to give some work to the unemployed and give a fillip to business; second, the organization of a national system of employment exchanges so that the labor market, which is a disorganized market, will become an organized market and employers will be brought closer to employees; and third, unemployment insurance.

I don't think we in the United States have gone much beyond that. The British Government has organized a system of employment offices since 1909, and they have been in operation since then. We are in the act of organizing a national system of employment offices. The British have had a universal system of unemployment insurance and have used public works.

These are the three traditional methods of dealing with unemployment. We have used them and it is pretty clear to everyone now that they are not solutions. They are not solutions in the sense that the application of these measures to the unemployment problem will result in a reduction of the volume of unemployment, because, after all, the real solution or approach to the unemployment problem is the application of a method which leaves the country with a smaller volume of unemployment than it had before.

It is true that if you have persistent unemployment, the use of employment offices for re-employment and work, and unemployment insurance may alleviate the difficulties; but it is pretty clear by this time that it doesn't reduce the volume of unemployment.

I turn then from this introductory statement to what it is that people think this unemployment is due. What do the people believe about unemployment? Well, one group believes it is due to one simple thing. They trace the increase in the volume of unemployment in this country (though they don't speak about other countries) to the increasing acceleration in the use of technical invention in industry and to the phenomenon associated with that—the increasing productivity of labor. This is a scientific problem I'd like to talk about, not from a theoretical point of view because that would take too long and take us farther afield than I am in a position to go at this moment.

What about this increase in technology? What kind of evidence is there to support the view that a serious unemployment problem grows out of the accelerated rate of application of invention to industry?

There are all kinds of evidence; there are many approaches to this question. I'd like to say one word first about how to measure these things. The measure of the increase is what we call the "productivity of labor," and this is measured in a direct way. You get a measure of physical production and you compare that measure of physical production with the number of people employed to get a measure of per-capita production. If you do that over a long period of time you have a comparative measure.

Another, and better, measure is to compute the amount of production per man-hour. Hence, in economic writings we have these two measures of what might be called the efficiency of labor—physical output, and man-hour physical output.

The trouble with those measures is that they are new and comparisons cannot be extended very far back in the records of economic history. That is a common scientific difficulty. It is going to take a long time before the records will reach back far enough and in good enough shape to make them comparable with contemporary records.

The History of Wages

I have been working on the history of wages in the United States from 1890 to date and I find my figures are better from 1914 to date than they were from 1890 to 1914. But I am interested in the period 1890 to 1914—a period of very bad depression and a business recovery; and as a scientific and economic historian I'd like to know how wages behaved in the depression of the 1890's, and in the recovery of that period, so that I can compare the recovery wages with wages in 1921, 1930 to 1933, and so on. It is going to take a lot of work and money—the same sort of work that the men in the natural sciences had to do before they built up their systems of measurement—before we can write the wage history of the United States from 1890 to 1914 and particularly from 1890 to 1900.

The same thing is true in productivity measures. We don't have a long enough series that is comparable over a long enough period of time. Another difficulty is this: Physical output is compared with the number of people employed. Well, the first thing any man that knows his methods of measurement must do is to make certain that he is comparing a physical output that was produced by employees for which he has an employment measure. Now, if I am comparing the physical output of one group of employees with the number of employees in another group, then I do not have a satisfactory final measure of the per capita physical output in the United States.

If you examine the unemployment figures for the year 1929, you find we have a moderately low unemployment rate. From 1922 to 1929 was a period of enormous rise in the productivity of labor and, however measured, the net cumulative effect at the end of that period, before we went into the depression, was a relatively low rate of unemployment. It was about four per cent, and it was really lower than that because in the United States we have decided changes in seasonal employment.

Now, I don't know what the normal rate of unemployment is in the United States; but with a gainfully occupied population in 1929 of about 50 million, a rate of four per cent or two million people, part of whom were—and I might say 30 per cent, anyhow—seasonally unemployed, is not high.

So, in my judgment, the technological problem that we had in the United States from 1922 to 1929 was a relatively moderate one. Given prosperity, without the great volume of unemployment associated with business depression, and the handling of that problem of displacement through the introduction of machinery was a relatively minor problem for a rich and going economic concern to deal with. It is true that we didn't deal with it and didn't have machinery to deal with it, but from the standpoint of analysis of the problem it was a perfectly practical thing to deal with and could have been dealt with, and not expensively.

Relation of Employment to Production

In a report of the National Resources Committee on technological change in the United States it is estimated that in order to absorb all the unemployed in the United States in 1937, in view of the great changes in the productivity of labor, it would be necessary to have a volume of production 20 per cent greater than in 1929. That is probably true. Every time we have had a business recovery, our index number of production ascended to a substantially new and higher level. The recovery from 1933 to 1937 was the first of which we have any record in which the index number of production did not exceed that in the preceding period of business recovery. It is also the first period of business recovery of which we have any record in the United States in which most of the people unemployed were not absorbed during the period.

One way to find out whether this continuing large volume of unemployment in 1933 to 1937 was due to technology is to find out where it is. That will not give a final answer, but it may throw some light on the problem. Does it exist in industries that have made great technological strides forward and in which there has been a great increase in the productivity of labor, or does it exist somewhere else? Well, I haven't made a careful study of this, but I have looked around, and I think that the unemployment we had in the recovery period 1933 to 1937 was in depressed industries—not in industries that had made great technological advances but in industries that stayed depressed. And while I don't know as much about these industries as I'd like to know, I am tempted to state this conclusion: they were industries that had not made sufficient technological advance. I might say that if they were industries that had been able to attract more capital and had then applied more invention to their operations, and so increased the productivity of their workmen, they would have employed more people than they did and we would have had a net lower volume of unemployment from 1933 to 1937.

Let us look at a few of those industries, because they are interesting in a number of ways.

First were anthracite, railroads, and building construction, and I associated with them subsidiary industries. I calculated their payroll during the expansion period 1933 to 1937 and compared it with 1929. So I had for each of these industries figures that told me how much payroll these industries yielded to labor in this country in this last recovery compared with the last year of the previous recovery, 1929. They are extraordinarily interesting figures.

The anthracite industry paid out in wages during this period of prosperity half what it did in 1929; railroads paid out 57½ per cent, and building construction, with all of the recovery we had up to and through 1937, paid out 35 per cent. The deficiency in anthracite is 50 per cent, of the railroads 43 per cent, and in building 65 per cent. Those are big deficiencies, and nobody for a moment will look at these industries, particularly the building industry, which is one of the two largest of this group, and say the trouble here is that people are working too fast, that their productivity has gone up too fast.

I don't want to take too much time on this, but we ought to consider the fact that back of the building industry are other industries that go up when building goes up—manufacturing industries as well as those occupations and services that are associated also with the prosperous industries. Of the associated manufacturing industries, the lumber industry employed 500,000 people in the United States in 1929—a big industry, as big as textiles. Its payrolls were, from 1933 to 1937 on a 1929 base: mill work, 40 per cent; saw mills, 40 per cent—a 60-per cent deficiency. So there is the picture. I haven't made a canvass of all these directly affiliated industries, not to speak of those indirectly affiliated, but I can attribute a great share of the volume of unemployment to industries that saw no technological improvement and in which unemployment persisted for the simple, traditional, and ancient reason that there wasn't any business.

So we are back to our old problem of why there isn't business. The technological advance isn't going to explain it. A study of unemployment in England won't ex-

plain it at all. What is it all due to? Maladjustment! That is the key to the problem—maladjustments, dislocations. A competitive society is an integrated society. If it isn't, it just doesn't work right. The character of the integration isn't simple, but we know something about it, and we know that if some parts of it get out of gear the efficiency of the whole machine may be reduced. Some of the dislocation and maladjustment in our machine couldn't be helped. We might have handled it a little better, but it was a difficult problem and it unquestionably has been a source of a great deal of unemployment. I am referring to the dislocation and maladjustment that arose internationally.

We have had a serious, severe, fundamental, persistent, long-time maladjustment that unquestionably reflects itself in an increase in unemployment in the United States and in other countries. If you look at the British system there is no doubt that a portion of the unemployment arose out of the changed international situation. Why do we have so much agricultural unemployment? One reason is that our position in the world markets is changed. But I want to talk about maladjustments closer at home and to look at them in broad terms.

Rapidity of Social Changes

During the time of the industrial revolution (certainly in the 19th century) with its changes in the methods of production and the growth of a wage-earning class, and all of that complexity of change that took place in England, the United States, and Germany, some other things happened. There were social movements associated with these economic changes. One of these was the trade-union movement. Another phase of the social movement was a growing interest of government in social conditions, in economic conditions, particularly in the economic conditions of employees. So the period from 1850 on to a large degree in Germany, to a larger degree in England, and to some slight degree in the United States, was characterized by the growth of instruments of reform the purpose of which was to stop exploitation, as it was called, to reduce the hours of work, to raise real standards of wages, and so on.

Now, if you look at those instruments and really take a broad view of their history, up to the war, I think you will find one interesting quality they all possessed: they all concerned minorities. The trade-union movements were of minorities, not only in the United States, but in England, Germany, France, and all industrial countries. And while they had some power, you can't talk about their power in the same terms as the sort of power they have possessed since the war. They were minority movements with definite workable restrictions on what they could do for better or worse or for good or ill.

The labor legislation that was applied had also a distinguishing quality. It was applied slowly and the changes it brought about were relatively slight changes. Look back over the history of wages and you will see the changes were very slow and were moderate. You can measure these things by looking at a country like England, where the hours of work in manufacturing industries even now are about 49 a week. But before the war the striking fact about these historical developments was that they were slow and moderate, and if you could have translated them into cost, their cost couldn't have been great. They were always applied to an industry that was expanding. That was true in the United States, England, and Germany, and in some measure in France. Thus, the conclusion one would draw from that history is that these efforts to control through trade unionism and labor legislation were of such a character that there wasn't any question that they could be easily absorbed by the economic system. That is all, and I think you can draw the general conclusion, if you look at an economic system as a going concern, that if you reform it carefully and in moderation it will stand a great deal of reforming; but if you reform it recklessly and without moderation your reforms probably will do a great deal more harm than good.

I think the character of reforms before the war was slow and moderate; and while there may have been occasions when they were difficult to absorb, taking the period as a whole they were easily absorbed. The reforms we have had since 1920 have been of just the opposite character, and the probabilities are that they will take a very long time to absorb.

I don't want to give the impression that this is the whole story, but it is a big part of the story. If the failure to run smoothly can be traced back to the rise and growth of dislocations and maladjustments of this kind, the speed with which we have applied these reforms—and they are costly reforms to the system—is one of the several fundamental causes of this failure to run smoothly and failure to absorb reforms.

All you have to do is take a look at them—the NIRA, all the labor boards, the Bituminous Coal Conservation Act, universal unemployment insurance, universal old age—I am using "universal" broadly, covering a large part of the population—numerous grants in aid, a federal system of relief, and public works. I have probably forgotten some, but that is a pretty big bite to take of reform. Somebody pays for these things and they entail burdens. Burdens of that kind imposed over a period of time can be absorbed with a minimum of dislocation and maladjustment and therefore of unemployment. Imposed in a short period of time they become hard to absorb.

We have measures of these things, and I think we are going to come closer to an understanding of these problems if we are able to translate some of them into magnitudes. Most people have had some business experience and can see how it becomes necessary to absorb these items of cost as we go along, and not only to absorb them at one time but to adjust them at another time. For example, when a business passes from a period of prosperity to a period of depression, one of the great problems is to adjust itself to this new type of business condition. I would like to give a few figures about manufacturing wages in the United States, and they are about as accurate as we have.

The manufacturing industries of this country, when things are going well, employ about ten million people, which is about 25 per cent of the total gainfully occupied.

When they are not going well they employ about seven or eight million people. So when you are studying wages in the manufacturing industries you are studying the wage of a large segment of the working population of this country. Eighty per cent are men, twenty per cent women, and industries covered in manufacturing run all the way from printing and publishing houses and rubber-tire industries, automobiles—in which wages are very high—to the canning industry, to the cotton-goods industry—where wages are relatively low. You can't talk generally about high and low wages in this country. They have got to be related to some standard. What do I mean by standard? American wages are high or American wages are low; obviously I have different things in mind. If I say American wages are high I mean, among other things, that they are high compared with what people get in other countries. I may also mean compared with what people used to get here.

Here are some figures of movement of wages in the United States in manufacturing industries: These ten million or so people were paid 25 cents an hour in 1914. They got 61 cents an hour in 1920. They got 59 cents an hour in 1929. At the bottom of the last depression, 1933, they got 45 cents an hour. And in December 1937, they got 72 cents an hour. That is a very important set of figures. In December 1937 manufacturing labor in the United States got, roughly, three times in money wage what it got in 1914. It got 11 cents an hour more than it got in 1920, which was the all-time peak of money wages in this country, and a peak that was reached after a very lively period of business from 1914 to 1920. And it got 13 cents more than in 1929, which was another peak in American business. It got 27 cents an hour more than it got at the low of the depression in 1933.

They are startling figures, and they are quite representative of wages generally. The only industries where wages have not moved like that are those in which labor got little reduction during the depression—railroads and coal.

Comparison of Real and Money Wages

Money wages should be translated into real wages because everyone knows that money wages lose their meaning in a period of radical changes in the price level. So I have converted these money wages into real wages—real hourly earnings, that is, money earnings corrected for the cost of living.

In December 1937, wages were 72 cents an hour as compared with 61 cents an hour in 1920, and of course, they were higher than in 1929 and much higher than in 1914, because comparing 1914 with 1937 money wages went up threefold and the cost of living went up about 50 per cent, so you have an enormous increase in real wages.

I want to make myself clear about this. I do not think that the population of a country like the United States divides itself naturally into two groups of people, one the friend of the masses, and the other the enemy of the masses, the friends wanting to sustain the so-called wages of labor and the enemies wanting to cut it down. I do not think that is a statement of the problem. When I say that industry has a capacity to absorb and when that capacity is exceeded it ceases to absorb and run smoothly, I mean that when friends of labor seek to put wages at a point where they cease to yield the greatest volume of employment and payroll, a great and perhaps lasting disservice is being done to labor by the very people who call themselves, and probably honestly regard themselves, as the friends of labor.

Now I am not so foolish as to say that I know what that point is, nor that I am prepared to say what wages fixed at that point would yield the highest payrolls to the largest number of employed people; but I think here, as in other cases, the rules of common sense might be applied. There are methods of observation that permit students to look at this situation; and here an excess has been practiced, and most people associated with it would have been better off if the excess had not been practiced.

In dealing with these kinds of problems, sooner or later we must come to grips with this conflict between our political views and our economic views, and there isn't going to be any right thinking, if, when we take the political point of view, we are willing to fall into gross economic error. If we fall into gross economic error that way and stay there, our economic problems are going to multiply and become more serious and more difficult to solve; and among the most serious and most difficult to solve will be this continuing unemployment problem, the persistence of a rate of unemployment in this country, as in England, at a level higher than it ever was before the war, at a level higher than it was in the prosperity period 1933 to 1937.

An Analysis of the Induction Machine

A MATHEMATICAL analysis of the induction machine which is applicable to the solution of a variety of transient and steady-state problems is presented in this paper.* The method was developed particularly to evaluate the performance of induction motors when driving pulsating loads such as compressors.

By means of a set of linear transformations, the phase voltages, currents, and flux linkages are referred to a set of orthogonal co-ordinate axes which are stationary with respect to the stator. The resulting differential equations are not only linear but have constant coefficients for the case where the rotor speed is constant. Such equations are readily solvable by the operational methods. The simplified equations are applicable to any machine with a uniform air gap and balanced, sinusoidally distributed rotor windings.

The treatment is not limited to problems wherein constant rotor speed is maintained. The results are expected to be especially useful in the practical solution of problems due to the excessive current pulsations and light flicker which may result when induction motors are used on pulsating loads.

*Abstract of 1938 AIEE summer convention paper number 38-69, by H. C. Stanley (A'37), which will be published in full in TRANSACTIONS.

Transcontinental Telephone Lines

By J. J. PILLIOD
FELLOW AIEE

Late in 1937 a large construction project was completed which added 16 telephone circuits to the transcontinental layout, and the work was so planned that 48 additional circuits can be obtained by the addition of equipment but without stringing additional wire. A brief description of some features of this project and the general development of the transcontinental telephone routes since the first one was opened for service in 1915 is given in this article. Although most of the discussion relates to transcontinental lines, the methods described are generally applicable to other similar situations.

LESS THAN 25 years ago, it was impossible to talk by telephone from coast to coast across the United States. Furthermore, it was impossible to talk between points separated by any such distance anywhere in the world. By 1915, technological advancement had reached a point such that telephone service could be established across the country, and three telephone circuits had been built which connected San Francisco and the Pacific Coast with points in the East. Four telegraph circuits were also provided by the new wires. An improved loading system and especially the successful development of the vacuum-tube telephone repeater were outstanding factors which made telephone connections of such length possible for the first time in history.

Open-wire lines played the major role in the early transcontinental telephone circuits. The transmission losses caused by cable were so great that it was avoided wherever possible. The steady improvement of telephone repeaters, types of loading for use on cable circuits, and carrier telephone systems for use on open-wire lines made it possible to provide rapidly and economically more telephone circuits across the continent as use of the service grew. In the cross section just west of Denver there are today 140 through telephone circuits and about the same number of telegraph circuits carried by four open-wire routes, the last of which was completed during 1937. While open wire was used almost exclusively as a matter of necessity in the first transcontinental telephone lines, cable is now used for about half of the circuit mileage. This is a striking illustration of the large-scale changes which have taken place in the interest of more reliable toll telephone service.

Continued Importance of Open-Wire Lines

The open-wire line seems destined to continue to play an important part in long-distance telephone communication, particularly where distances are great and circuit requirements on any one route are relatively small. Improvements in the usage to which the wires may be put have made this increasingly so. The three circuits on the first transcontinental line were operated at voice frequencies and were obtained from two pairs of line conductors, the third circuit being derived by means of phantom circuit arrangement of these two pairs. The development of carrier telephone systems made it possible to obtain three additional circuits on some pairs of wires, using frequencies above those required for existing voice-frequency circuits. Carrier telephone systems were first installed on a transcontinental route in 1926 and were quickly followed by others, so that today 96 of the 140 circuits mentioned earlier are obtained by means of these three-channel carrier telephone systems. Development work, however, has been continued, and it is now expected that it will be possible, by means of carrier telephone systems using still higher frequencies, to obtain as many as 12 more telephone circuits on some pairs of wires. It has been with a view toward using such systems and obtaining a total of 16 telephone circuits on a pair of wires that the latest of the four transcontinental routes has been designed.

Construction of New Transcontinental Line

Early in 1937, it became clear from a study of loads carried on existing transcontinental routes that additional circuits would be required in the near future. Circuits in cable were available as far west as Omaha, Kansas City, Oklahoma City, and Dallas. After consideration of all the factors, it was decided to construct the new facilities west from Oklahoma City to Los Angeles on the route shown in figure 1. It was also decided to carry out the work in such a way that the route could be utilized for the future addition of a relatively large number of circuits through the application of the 12-channel carrier-current telephone system then under development. Among the conditions favoring this particular route is freedom from winter storm hazards throughout most of the distance, which, looking ahead, is particularly important to the future application of 12-channel carrier telephone systems. The work done in 1937 consisted of building a length of nearly 300 miles of new pole line and stringing four pairs of wires throughout most of the section from Oklahoma City to Whitewater, Calif., a distance of 1,200 miles. Ini-

Essential substance of an address presented before the communication group of the AIEE New York Section, March 22, 1938.

J. J. PILLIOD is engineer, American Telephone and Telegraph Company, New York, N. Y. A native of Chillicothe, Mo., he was graduated from Ohio Northern University with the degree of electrical engineer in 1908. He was employed in various departments of the American Telephone and Telegraph Company from that time until 1917, when he entered the long lines department at New York. Since 1920 he has been in charge of engineering in that department. During 1933–37 Mr. Pilliod was a member of the AIEE committee on communication.

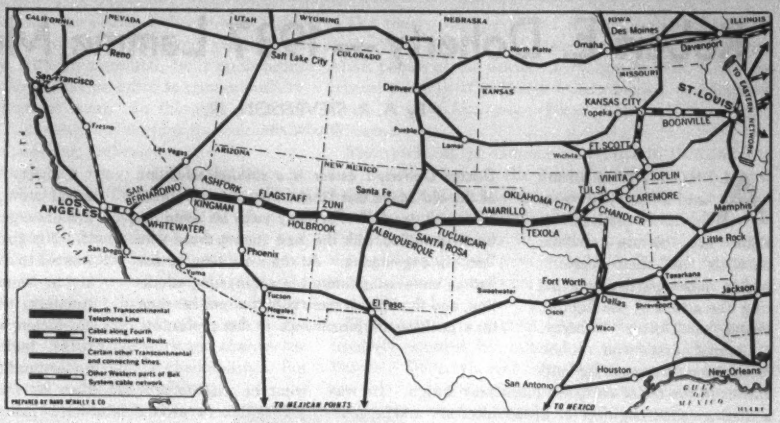

Figure 1. Route of new transcontinental line across western states

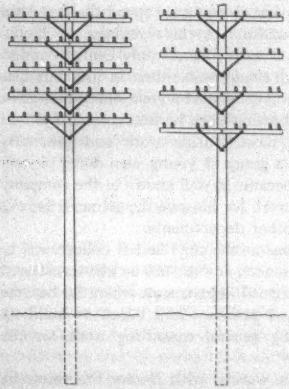

Figure 2. Cross-arm arrangements

Left—50-wire phantomed line, capacity 77 telephone circuits

Right—32-wire non-phantomed line, capacity 256 telephone circuits

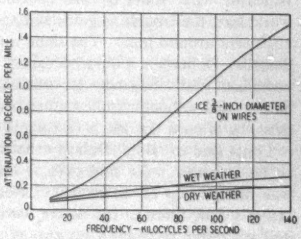

Figure 5. Attenuation of open-wire pairs

165-mil copper, 8-inch spacing

tially the voice channel and three-channel carrier telephone systems have been developed on these four pairs, providing a total of 16 telephone circuits.

Wire Spacing and Transpositions

Open-wire telephone lines designed to carry frequencies up to 140 kilocycles per second, as used in the operation of the proposed 12-channel carrier telephone systems, have structural requirements substantially more stringent than those designed to carry only three-channel systems, which use frequencies up to 28 kilocycles. The usual type of open-wire toll telephone line has ten wires on each crossarm, spaced at about one-foot intervals, five on each side of the pole and with the crossarms spaced 24 inches apart. In the case of the line designed to conduct high carrier telephone frequencies, this configuration has been changed and is illustrated by figure 2. Eight wires are strung on each arm, grouped as four pairs, two on each side of the pole. The wires of the pair are spaced 8 inches apart, and the nearest wires of the two pairs on each side of the pole are spaced 26 inches, while the spacing at the pole is 30 inches. Crossarms are spaced 36 inches apart.

These new wire spacings reduce the coupling between pairs on the same line or between pairs on this line and pairs on other lines which may parallel it. New transposition systems are used further to reduce this coupling. Transpositions are closer together and a transposition bracket of the type shown in figure 3 is used to turn the wires completely over at as nearly a given point as possible. Transpositions in one or more pairs are installed on every pole with an occasional exception, and certain pairs are transposed at every other pole. The wires of a pair must be adjusted to the same sag within close limits. These sag variations are held to a fraction of an inch, and

(*Concluded on page 423*)

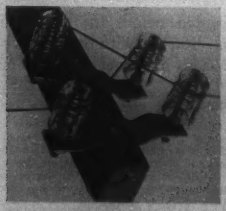

Figure 3. Point type transposition bracket as installed

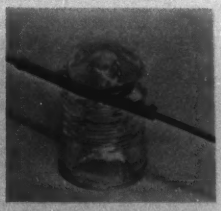

Figure 4. Flat tie wire shown as installed

Robert E. Doherty — 1937 Lamme Medalist

By A. R. STEVENSON, JR.
FELLOW AIEE

Doctor Doherty's career is a striking refutation of the old adage that "those who can, do; those who can't, teach." For many years his name has been identified with the best among those who "do" in engineering. At the same time he has had an unwavering interest in engineering education, and through his many contributions has risen to a position of prominence in that profession.

ALTHOUGH Lamme and Doherty grew up in rival institutions, there are certain striking parallels in their careers, which make particularly fitting the award of the Lamme medal to Doctor Doherty.

Lamme first won public recognition by making advances in the art of electrical machinery design. He was a distinguished engineer of broad interests and a great educator who, while he was continuing his engineering work, took the trouble to guide and encourage the younger engineers around him. The same words could be used to describe Doherty's industrial career. Although Lamme remained with industry, he was none the less an educator; and although Doherty has become a college president, he is none the less a distinguished engineer.

I once said to "Bob" Doherty that it would be very nice to be a farmer. He said "No, I know all about it. I was brought up on a farm." Later he worked in his father's drug store in his native town of Clay City, Ill.; and still later he worked for two years as a telegrapher.

He took a great interest in music and made an intensive study of musical composition. Generally books on artistic subjects consist of a great many unrelated "don'ts," with very few constructive, positive, general principles. "Bob" Doherty constructed for himself half a dozen general principles, and wrote a piece for the band in his home town. Unfortunately, he did not realize in the beginning that music for certain band instruments is written in one key and played in another; consequently, the first time the band tried to practice his piece the effect was horrible. After these technical difficulties were corrected, however, the band was so pleased that it used Doherty's composition as a special exhibition piece all one summer.

A Definite Goal

At college he was active in undergraduate affairs as well as in the classroom, serving on various committees and playing in the college band. Evidence of his proficiency and standing as a student is attested by his election to membership in Tau Beta Pi, Eta Kappa Nu, and Sigma Xi. After he was graduated from the University of Illinois with the degree of bachelor of science in electrical engineering in 1909 he entered the students' training course at the Schenectady works of the General Electric Company in the same year, and after two years in the testing department, joined the a-c engineering department as a designing engineer.

Doherty is one of the few men I know who has always had a definite goal and has stuck to it. His goal was two-fold: He wanted to do engineering work and he wanted to teach. Fortunately, these two goals are not incompatible.

He had a passion for understanding thoroughly what he was doing; and when he found that some of the designers around him were using formulas which they really did not understand, he decided that regardless of the pressure of work he would spend the first hour every morning, in addition to his evenings, in fundamental studies. As a result, he not only came to understand the bases for all the formulas then in use, but also he improved them and developed a great many new ones. This consulting-engineering work became so valuable that he was relieved of most routine work and gradually collected under him a group of young men doing pioneer work. His section became so well known in the company that in addition to work for his own department, he was consulted by many other departments....

One of his ambitions at the time he left college was to work for Doctor Steinmetz, and in 1920 he was transferred to the engineering general department, where he became Steinmetz's right-hand assistant and began to build up a small section doing general consulting work for the whole company.

During the time he worked with Doctor Steinmetz he took postgraduate work at Union College, receiving the degree of master of science in 1921. In 1922 he was given the title of consulting engineer. In that position his work was principally general consultation on engineering problems. The largest projects related to power transmission and to the behavior of electrical machinery under abnormal conditions.

Doherty's Scientific Stature

His technical papers presented before the Institute cover a wide range of subjects. Starting with the Doherty and Shirley paper on synchronous-machine reactance in

An address delivered on the occasion of the presentation of the Lamme Medal for 1937 to Doctor Doherty, at the AIEE summer convention, Washington, D. C., June 21, 1938.

A. R. STEVENSON, JR., a former associate of Doctor Doherty, was graduated from Princeton University with the degree of civil engineer in 1914. In 1915 he received the degree of master of science in electrical engineering at Union College, and two years later the same institution granted him the degree of doctor of philosophy. Following his graduation in 1917 he served for two years in the Air Corps of the United States Army during the World War, then joined the General Electric Company. In 1923 he was appointed to the staff of the vice-president in charge of engineering, and now holds the position of assistant to the vice-president.

1. For all numbered references, see list at end of article.

1918 and going through the classic Doherty and Nickle series of papers on synchronous-machine performance during 1926–30, he, with his associates, built up a theory of salient-pole machines that promises to remain authoritative for many years to come. In this field alone his contributions and leadership entitle him to rank in the forefront of the engineering profession.

While he was carrying a heavy load at the office he had time to serve efficiently on the school board, and for one year was mayor of the village of Scotia, where he lived, and where again he demonstrated his ability as a leader. His qualities of leadership are evident throughout his scientific work. In each instance he had the vision and initiative to plan the project and the persistence to see that it was finished, but he gave his associates and students the opportunity of sharing the creative work and always was the first to give them credit and praise their ability. For instance, in commenting on the series of five papers which he and Nickle wrote, he always says, "Most of the work in the last three papers of the series was primarily due to Nickle." I know, however, how much time he devoted to this work with Nickle.

Some of his scientific contributions can be outlined further, the joint authorship of most of these papers indicating the team work which was developed under Doherty's leadership.

Doctor Doherty

Papers on Reactance

Before 1918 fundamental theory and data were reasonably adequate for the calculation of operating characteristics of machines with cylindrical rotors. The application of the existing theories and data to salient-pole machines led to trouble in the form of excessive oscillations and of undesirable division of load on synchronous frequency converters. Steinmetz and others already had made theoretical progress based on Blondel's fundamental conception of resolving the space distribution of the fields about the two axes of symmetry. This preliminary theory could not be applied satisfactorily, however, because it involved characteristic coefficients which at that time were not being determined rationally from design-sheet data. Doherty developed a method of determining these fundamental coefficients quantitatively from graphical flux plots based upon design-sheet data using the already existing theories of flux plotting.

This determination not only made possible the calculation of the much-needed "quadrature-axis synchronous reactance," thus rendering available the equation for the flux distribution over the armature surface; but also it made possible the rational determination of other design constants. More important, it cleared the way for further extensions of fundamental theory.

In this early work Doherty was assisted by Henningsen, Shirley, and Wieseman. The first public reference to the method was in the 1918 AIEE paper "Reactance of Synchronous Machines and Its Applications,"[1] by Doherty and Shirley.

The theory was developed further by associates and students of Doherty and presented in a series of three AIEE papers at the winter convention in 1927, under the general heading "Graphical Determination of Magnetic Fields,"[2–4] by Stevenson, Park, Johnson, Greene, and Wieseman.

Meanwhile, at the summer convention in 1926 Doherty and Nickle presented the first of a series of five papers setting forth the newly developed theory for salient-pole machines under the heading "An Extension of Blondel's Two-Reaction Theory."[5] Later important generalizations and refinements were made by R. H. Park,[6] an associate of Doherty, and were presented to the AIEE in 1928 and 1929.

Flux plotting is of great importance and has been intensively studied by others,[7–11] notably Lehmann in France. Doherty's real contribution was its adaptation to the solution of practical problems which had previously baffled designers.

The Constant-Linkage Theorem

When Doherty was a student engineer testing transformers at Pittsfield he had an experience that impressed forcibly on his mind the fact that there is a certain inertia or resistance to change involved in an interlinkage of magnetic flux and windings. While he was measuring the resistance of one winding of a large power transformer by the voltage-current method, Doherty short-circuited the other winding just prior to opening the power circuit. This was for the purpose of minimizing the arc and the induced voltage. After disconnecting the d-c power circuit, he descended the ladder upon which he had been standing, picked up a tool he had dropped, ascended the ladder, and then opened the short-circuited winding. Much to his surprise and subsequent delight, a large arc was drawn. He had learned, in a not-to-be-forgotten way, the meaning of the term "time constant."

Doherty first stated the constant-linkage theorem incidentally in the 1918 paper already mentioned, and formally presented proof in 1923 under the title "A Simplified Method of Analyzing Short-Circuit Problems."[12] This made easily possible the visualization and calculation of short-circuit phenomena which before had been regarded as of complex nature, and provided an additional block in the foundation on which the later extensions of theory were built.

The use of flux plots in determining characteristic constants of synchronous machines from design data and the constant-linkage theorem are the foundation of all the succeeding work in theory. If these two initial steps were taken out, the foundation would be missing.

Short Circuits on Induction Machines

One direct result of the constant-linkage theorem was Doherty's demonstration that, quite contrary to the gen-

eral belief of leading engineers, the initial short-circuit current of an induction generator was of the same order of magnitude as that of a synchronous machine of the same size. Commercial propositions were being prepared in 1919 on large induction generators on the grounds that they would not add to the initial short-circuit current of the system. Doherty and E. T. Williamson presented a paper at the AIEE winter convention in 1921 on "Short Circuit Current of Induction Motors and Generators,"[13] which changed the existing point of view and explained certain puzzling transient phenomena in such machines.

Exciter Instability

Complaints of loss or reversal of excitation on large a-c generators led to this investigation. Doherty showed that the equation for the excitation current of the alternator field was of the same form as that for the current in a circuit containing inductance, capacitance, and resistance, and therefore the exciter armature current might involve transient oscillations. This was confirmed by experiment, and the results were presented in a paper "Exciter Instability,"[14] presented at the Seattle convention in 1922.

Flywheels

The paper presented by Doherty and Franklin before the winter convention of the American Society of Mechanical Engineers in 1920, "Design of Flywheels for Reciprocating Machinery Connected to Synchronous Generators of Motors"[15] did not introduce a complete new theory but adapted existing dormant theory to the solution of another problem that had baffled designers.

This paper was of great importance in furnishing the basis for calculating the proper flywheel effect for synchronous units coupled directly to reciprocating apparatus such as oil or gas engines and air or ammonia compressors, and led to papers by others on the same subject,[16–18] which further developed the theory and the usefulness of the method based on a co-operative study with the engine and compressor builders.

The foregoing concerns Doherty's contributions in laying a foundation for the solution of important, difficult, practical problems, and the further development and refinement of theory and methods by his associates and students, who were stimulated to these advances by association with Doherty.

Through his own experience and his contact with other young engineers, Doherty came to realize that additional education was necessary to bridge the gap between what was learned in college and the application of that and further knowledge to real engineering problems. There was a tendency for young men to give up the habit of study and forget the more technical things they had learned, when they got out of college and started on practical work. Consequently, when they finally reached an engineering department they tended to become simply "handbook" engineers instead of thinking from a fundamental, technical viewpoint.

In 1922, therefore, Doherty proposed that the company should have an advanced course in engineering. As a result of a review of the proposal with various department heads, it became evident that there was really a need for more engineers with a fundamental training that would enable them to think for themselves, and he was authorized to start the course. I was lucky enough to be selected by him as his assistant in founding this educational program. We started it in the fall of 1923, graduated the first one-year class in 1924, and the first three-year class in 1926. This course is described in "An Advanced Course in Engineering"[19] and further detail here is unnecessary.

Out of the hundreds of young college graduates usually employed each year by the company, approximately 30 are chosen for a one-year course in which the fundamentals of science and engineering are reviewed, the chief object being to teach the students to think for themselves, to recognize the common fundamental bases of all engineering and to enable them to apply this fundamental scientific thinking to the actual solution of practical engineering problems. After completion of this one-year course, about half the men are selected to go on with two additional years of advanced study—some in electrical design, some in thermodynamics, and some in high frequency and electronics. Since the beginning in 1923, 429 men have been graduated from the one-year course and 115 men have completed the three-year course. The majority of these men have stayed with the company and are widely scattered throughout all its departments including engineering, manufacturing, commercial, and patent. Some of them have left the company and are doing good work, particularly in teaching.

Anyone who has run an educational institution knows how inevitably this leads to personnel work. As more and more advanced-course men began to be placed around the various departments, Doctor Doherty began to take more and more interest in the personnel of the departments, and was finally placed in charge of the engineering personnel. During this assignment he initiated and devised a series of rating sheets and personally visited all the engineering departments to help the department heads rate their men.

In April 1931, he was appointed professor of electrical engineering at Yale. In November 1932 he became dean of the new school of engineering at Yale.

During the past few years his contributions to the literature of engineering education, through the Society for the Promotion of Engineering Education and the Institute, have brought him wide recognition as a leader in formulating a modern philosophy of education. He believes in training men to think for themselves, to search out and make use of facts, and to measure their achievements by the service rendered to society. Most important of all, he is finding new ways to accomplish these objectives, and with unexampled energy is pressing engineering education to renewed progress.

In March 1936, he became president of Carnegie Institute of Technology. In that year he received the honorary degree of doctor of laws from Tufts College and from the University of Pittsburgh.

Those of us who know Doctor Doherty best feel that the Carnegie Institute of Technology made a very wise choice.

He is an engineer and an educator with definite, forward-looking plans for the improvement of engineering education. He is a fine executive, capable of carrying out his plans, and he is an all-round man interested in cultural as well as engineering subjects. For instance, he is very much interested in painting and several of his paintings have been exhibited. It is a particular gratification to him that Carnegie Institute of Technology is not only an engineering school but also includes a college of fine arts.

Doherty has always taken a great interest in his associates and has helped them to advance by stimulation and by going out of his way to give them full credit and praise for their accomplishments. This ability to appreciate his fellows genuinely has warmed the hearts of all his friends. Wherever "Bob" Doherty has been he has left behind a devoted circle of close friends, who continue to long for his stimulating society.

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Transcontinental Telephone Lines

(*Continued from page 419*)

a check of the completed work indicated that 50 per cent of the spans had been adjusted to within one-quarter inch. Telescopes are used to help obtain these close sag adjustments, and a final check is made by oscillating the wires in a span and observing the periods at which they oscillate.

Pole Spacing and Insulators

Poles must be spaced uniformly in order that the transpositions may be most effective, and an occasional deviation of only 35 feet is the maximum permitted. Where it is impossible to locate poles within this limit, such as is the case at long-span crossings, special fixtures are suspended from steel cables at the proper points to permit making the transpositions.

New types of insulators on steel pins, each pair of which is electrically bonded, are used to improve the stability of the transmission characteristics.

Wire 165 mils in diameter was used on this construction west of Oklahoma City because of its strength and resultant relative freedom from interruptions. Transmission losses were also a factor in this case. Rolled sleeve joints were used in splicing the wire because of their strength and good electrical characteristics. Flat tie wires, shown in figure 4, were used to reduce chafing of the line wire when the wires vibrate. Tie wires are not used at transposition points, as may be seen in figure 3.

Repeater Stations

The computed losses on open-wire pairs of this type at high-carrier frequencies and under different weather conditions are shown by figure 5. Field tests confirm these data. To offset the line losses it will be necessary to locate repeater stations at intervals of from 50 to 100 miles, depending upon the weather conditions which may be expected. Between Oklahoma City and Whitewater, Calif., in order to operate the 12-channel carrier telephone systems, it will be necessary to equip 16 intermediate repeater stations. Most of these will be unattended and maintained from other offices.

It is not practicable, of course, to bring the open-wire pairs directly into all repeater stations and in some cases entrance cables several miles long must be used. Although ordinary nonloaded cable pairs may be used for this purpose, their usage involves transmission difficulties, and except where other factors dictate the use of this type of facility, it is planned to use low-loss cable conductors of a new design. These cable pairs have more favorable impedance characteristics as well as lower losses.

With the building and the further equipping of this latest open-wire line across the western states, open-wire facilities have played one more important part in the development of long-distance telephony. Although cable is being found more and more useful, there still remain many important links in the nation-wide telephone communication network where, for the present at least, the open-wire line can serve best and the development of it toward maximum usefulness is still being carried on.

News
Of Institute and Related Activities

International Committees Consider Agreement on Electrical Problems

TO CARRY international standardization agreements another step forward, 400 delegates from 22 countries met at Torquay, England, June 22–July 1 for the ninth plenary meeting of the International Electrotechnical Commission; 22 delegates from the United States attended the nine-day meeting.

Besides several important final agreements—notably one to co-ordinate the methods of rating transformers in different countries by showing both the test rating and the service rating on the name plate, and an agreement covering the properties of aluminum for use as electrical conductors—many of the IEC committees made progress in their work. Welding was added to the IEC program for the first time, the committee on welding holding its organization meeting at Torquay.

After nearly 25 years of work on an international dictionary of electrical terms, the new "vocabulary" of nearly 2,000 definitions in both French and English, was approved finally for publication. A preliminary summary of some of the actions taken at the Torquay meeting follows.

International Electrotechnical Vocabulary. The first edition of the vocabulary, containing some 2,000 scientific and technical terms defined in both French and English, and with titles in German, Spanish, Italian, and Esperanto, was approved for publication. Copies will be sent to those interested. Comments received by these committees will be considered by the IEC in revising the vocabulary.

Transformers. Two divergent methods of rating transformers have been in general use in different countries: one based on the full-load secondary current and the no-load secondary voltage; and the other based on the full-load secondary current and the full-load secondary voltage at a specified power factor of 0.8 or 0.85. The IEC delegates at Torquay agreed that both the IEC test rating and the IEC service rating should be shown on the name plate. It was agreed also that if no power factor is specified by the purchaser the service rating will be based on a power factor of 0.8, and that losses should be expressed in kilowatts and not as a percentage efficiency. Fractional loads are to be expressed in terms of current. The test rating agreed upon by the IEC as one of the factors to be used in rating transformers defines a transformer in which it might be desired to reverse the direction of flow of power. The service rating defines a transformer with a predetermined direction of flow.

Ambient temperature was defined to mean that the peak value of 40 degrees centigrade should be associated with an average temperature not exceeding 35 degrees centigrade over any 24-hour period. The maximum temperature rise for oil-immersed transformers with forced oil circulation, it was agreed, should be 65 degrees centigrade.

Graphical Symbols. Proposed revisions of the IEC graphical symbols were considered. It was suggested that the national committees submit proposals for additional sections on electronic devices (rectifiers), time switches, and clocks.

Lamp Caps and Holders. Dimensions of lamp caps and holders, approved by this committee, will be published by the IEC. Drawings of gauges were approved, but each national committee will decide for itself what gauges shall be used for checking the dimensions.

Aluminum. It was unanimously agreed that annealed aluminum should be defined as aluminum which, in the form of a wire having a diameter of one millimeter or more, has a maximum tensile strength of 9.5 kilograms, and a minimum elongation of 20 per cent in a length of 200 millimeters. The measurement of the elongation is to be taken after fracture. The normal resistivity value should be 0.0278 ohm for a cross-sectional area of one square millimeter and a length of one meter at a temperature of 20 degrees centigrade. The temperature coefficient and density for hard-drawn aluminum are considered to be the same as for annealed aluminum. For the steel core it was agreed to adopt a tensile strength of 120 kilograms per square millimeter of cross section and an elongation of five per cent for wires having diameters of three millimeters or more, and four per cent for wires having diameters smaller than three millimeters. Standards of resistivity for aluminum used for insulated cables and bus bars were agreed upon.

Standard Voltages and High-Voltage Insulators. A column showing the voltages per phase corresponding to the phase-to-neutral voltages for a three-phase system will be included in the new edition of the IEC publication on standard voltages, in the section between 100 and 1,000 volts. The first edition of an international specification on the testing of insulators will be issued. Impulse test voltages for the testing of line insulators will be included.

A draft specification for testing bushing insulators was referred to the national committees for consideration, together with a similar draft specification for bushings, and a report recommending revision of the IEC calibration tables for sphere gaps was approved.

Electric Traction Equipment. A revised edition of the specification for traction motors will be circulated to the national committees for approval.

Radio Communication. Draft specifications for capacitors as used in radio receivers devices for suppressing radio interference and a specification for symbols relating to electrodes and electrical magnitudes of electronic tubes were considered, but no action was taken. A revised draft of proposed safety regulations for mains-operated radio receivers is to be prepared.

Electrical Instruments. Revision of the publications on a-c watt-hour meters, instrument transformers, and indicating instruments was discussed, and joint action will be taken later. This committee held a joint meeting with the advisory committee on terminal markings, and the two committees appointed a subcommittee to consider marking instrument transformers separately from instruments and meters.

Shellac. A report on progress in application of shellac in the electrical industry during the past three years was presented by the chairman, A. J. Gibson, of Great Britain.

Terminal Markings. A report by this committee summarized the systems of terminal markings now in use, as follows:

1. The system used in the United States as given in the American Standard for Rotation, Connections, and Terminal Markings for Electric Power Apparatus

2. The system used in Great Britain, which will be available soon as a report of the British Standards Institution

3. A composite system taking certain of its parts from the systems of the different nations on the continent of Europe, the composite being consummated in discussions of IEC advisory committee number 16

It is expected that the IEC now will print the composite system as a report, in the hope that as the various nations find a change in their existing systems necessary, they will be able to adopt this system in its entirety, or in part.

Electric and Magnetic Magnitudes and Units. The committee agreed to recommend that the connecting link between the electrical and mechanical units should be the permeability of free space (μ_0) with the value of 10^{-7} in the unrationalized system. The committee agreed also to recommend that the name of the unit of force be the "newton."

ASME Committee on Rubber and Plastics. A committee on rubber and plastics has been established by the American Society of Mechanical Engineers to deal with several phases of the rubber and plastics industries including mechanical application, research on basic mechanical properties, processing equipment, and standards. As one of its early activities, the committee will sponsor a symposium on rubber at the next meeting of the society to be held October 5–7, 1938, at Providence, R. I.

Southern District Meeting Offers Attractive Features

Plans for the AIEE Southern District meeting, to be held in Miami, Fla., November 28-30, 1938, now are practically complete. The program includes many papers of interest to the membership of the Institute, and the exceptional sport and recreational facilities available in Miami will provide abundant amusement for the guests and their families.

The program, as outlined, will consist of registration and opening of the meeting on the morning of Monday, November 28. The afternoon and evening of the opening day will be devoted to student activities under Professor E. F. Smith, as chairman, and will be followed by a student and counselor's dinner. Technical sessions Tuesday morning will be on transmission and distribution followed that afternoon by papers on education, economic, and sociological subjects. The technical session Wednesday morning will be devoted to papers on electrical generation and equipment. Wednesday afternoon will be devoted to special committee meetings, inspection trips, and recreation.

Many unusual opportunities exist for a variety of sports and recreation. The entire facilities of the Miami Biltmore Hotel and Country Club, which include its championship 18-hole golf course, fast clay tennis courts, and fresh water swimming pool will be at the disposal of members and guests. Available also will be the Roney Plaza Cabanas with a salt-water pool and private bathing beach, as well as the Key Largo Anglers Club Camp. These recreational facilities provide the best of equipment for golf, tennis, and bathing, as well as some of the finest salt water fishing which can be found in the United States.

Completion of the Overseas Highway, which joins Miami and Key West with a modern hard-surfaced automobile road, provides an interesting structural study for engineers, and a beautiful and colorful trip for those who travel it. Arrangements have been made which will enable those attending the meeting to take a trip to Cuba at nominal expense.

It is hoped that the members of the Southern District and others will plan to combine their attendance at the meeting with a vacation trip in order that they will have ample time to enjoy the many pleasures available to the visitors.

Details of the program will be announced in the November issue.

The personnel of the Southern District meeting committee is as follows: A. P. Michaels, chairman; E. D. Wood, vice-president, AIEE Southern District; A. S. Hoefflin, secretary, AIEE Southern District; E. E. George; E. F. Johnson; M. E. Lake; E. F. Smith; W. Austin Smith; and Joseph Weil. The chairmen of the subcommittees are as follows: J. C. Jones, *papers and program;* J. B. Hiers, Jr., *finance;* J. D. Preston, *attendance and publicity;* P. J. Carlin, *transportation;* R. Y. Pool, *entertainment;* and E. F. Johnson, *hotel and reservations.*

Symposium on Apparatus Rating Proposed for Winter Convention

FOLLOWING recent discussions in the standards and electrical machinery committees of the AIEE, the chairman of the latter committee has appointed a subcommittee, of which F. E. Harrell is chairman, to study the general questions of temperature limits and rating of small power apparatus. This committee has decided to sponsor a symposium on this subject which is proposed for the forthcoming winter convention in January 1939. Tentative arrangements have been made for the inclusion of this symposium on the program, subject of course to the approval of the papers submitted, with a full opportunity for discussion.

It is planned in this symposium to consider three general aspects of the rating problem: the temperature limits of insulating materials; the methods of determining hot-spot temperatures in machines; and the general principles of rating. The object of the symposium is primarily to formulate suggestions for revision and extension of the standards on general-purpose motors and similar small apparatus, especially with class *A* insulation. It is not proposed to discuss on this occasion the problems of rating of large or high-voltage apparatus, in which distinctly different insulating materials are used, and to which different operating conditions apply.

The general principles on which present temperature limits, in the rating of electrical apparatus, are based are given in AIEE Standards No. 1, prepared in 1925. These standards establish a continuous hot-spot temperature limit of 105 degrees centigrade for class *A* insulation and provide for a conventional allowance of 15 degrees centigrade between the temperature as measured by thermometer and the hottest spot. They also establish 40 degrees centigrade as the standard ambient temperature in determining the limiting temperature rise in apparatus rating.

In the past 15 years, many developments have occurred which suggest the need of reviewing this basic standard. Much new information has been accumulated on the life of insulating materials under different temperatures, and new materials have been developed not considered in the old standards. The committee, therefore, proposes to have one group of papers presented dealing with the new information on temperature endurance of various insulating materials now used or proposed for future use in small power apparatus. Plans as so far developed include a paper on the temperature-life characteristics of class *A* insulations, another paper on developments in glass insulation, and a third on the properties of magnet wire.

A second group of papers will deal with the question of hot-spot-temperature determination, and, in general, methods of specifying temperature limitations. One paper has so far been promised, dealing with temperature rise determination of induction motors, and other contributions are planned. A question at issue here is the extent to which resistance, instead of thermometer or thermocouple methods of measurement, should be used in determining motor temperatures. The recent trend toward the use of fan-cooled and enclosed motors of many types has made it increasingly difficult to get accurate thermometer readings of hot-spot temperature rise. On the other hand, the use of resistance measurements exclusively gives an average, rather than a maximum, temperature value and introduces new problems in the way of

A View of the Seven Mile Bridge from Pidgeon Key, part of the Miami-Key West Overseas Highway

simple and accurate measuring apparatus. It is hoped that discussion at the meeting will bring out new information on this important subject.

The third group of papers will deal with the general principles of rating of apparatus, including permissible overload limits under different duty cycles and different ambient temperatures. The philosophy of rating, as developed over the past 15 years, leads more and more to the complete separation of operating from rating standards. Rating standards are necessary to give definitely determinable and comparable conditions of performance. Apparatus with this single standard of rating, however, must be used under widely different conditions of loading, depending on ambient temperatures, operating conditions, and the desired economic life of the equipment.

Recognizing these considerations the new American standards for transformers, shortly to be published, will include recommendations for the operation of small transformers in accordance with temperature under various intermittent conditions of loading. The standards will permit short-time overload operation of transformers on a graduated basis, determined so as to give the same total insulation life of the transformer in years under all conditions. The recent developments in automatic duty cycles and short-time overloads for motors in air-conditioning, refrigeration, and many other household and industrial applications, indicate the need for corresponding revision of the American standards on motors.

The committee has so far planned to include four papers in the symposium on this aspect of the subject, one on the rating of general-purpose induction motors, another on the application of motors in the refrigeration industry, a third on rating principles in general, and a fourth on the experiences of the transformer committee, on which the new standards are based.

The committee invites suggestions in regard to additional papers and subjects to be considered. All communications should be addressed to: F. E. Harrell, chairman, AIEE subcommittee on rating of electrical machinery and apparatus, care of The Reliance Electric and Engineering Company, 1068–1088 Ivanhoe Road, Cleveland, Ohio.

Future AIEE Meetings

Southern District Meeting
Miami, Fla., November 28–30, 1938

Winter Convention
New York, N. Y., January 23–27, 1939

South West District Meeting
Houston, Texas, Spring, 1939

North Eastern District Meeting
Springfield, Mass., May 1939

Summer and Pacific Coast Convention (combined)
San Francisco, Calif., June 26–30, 1939

Middle Eastern District Meeting
Scranton, Pa., October 11–13, 1939

Great Lakes District Meeting
Minneapolis, Minn., Fall, 1939

Chemistry Subcommittee of NRC Insulation Committee Meets at Milwaukee

FOR THE third successive year the attention of chemists meeting in national assembly has been directed toward the problems of electrical insulation. In each instance the discussion of dielectric phenomena has been held under the joint auspices of the American Chemical Society and the subcommittee on chemistry of the committee on insulation of the National Research Council, division of industrial and engineering research. The 1938 conference was held at Milwaukee, Wis., September 8, most important business of which was a symposium under the chairmanship of Doctor F. L. Miller, of the Esso Laboratories, Standard Oil Development Company, Linden, N. J. This report has been made available to readers of ELECTRICAL ENGINEERING through the courtesy of Doctor F. M. Clark (A'24), General Electric Company, Pittsfield, Mass.

At the symposium, which was attended by approximately 125 chemists and engineers, four papers were presented and discussed:

1. LIQUID DIELECTRICS—SOME CHEMICAL, PHYSICAL, AND ELECTRICAL PROPERTIES OF SYSTEMS CONTAINING LEAD OR COPPER SOAPS IN LIQUID PARAFFIN, **John D. Piper, A. G. Fleiger, C. C. Smith** (A'29), **and N. A. Kerstein**, The Detroit Edison Company, Detroit, Mich.

2. A CRITICAL STUDY OF SOME TESTS USED IN THE INVESTIGATION OF INSULATING-OIL DETERIORATION, **J. C. Balsbaugh** (A'23, M'35) **and J. L. Onclay**, Massachusetts Institute of Technology, Cambridge.

3. CHEMICAL FACTORS INFLUENCING THE STABILITY OF MINERAL-OIL-TREATED INSULATION, **F. M. Clark** (A'24), General Electric Company, Pittsfield, Mass.

4. THE ELECTRICAL APPLICATION OF POLYSTYRENE, **L. A. Matheson** and **W. C. Goggin**, Dow Chemical Company, Midland, Mich.

During brief introductory remarks the members and guests were welcomed by Doctor H. S. Gardner, secretary of the division of industrial and engineering chemistry of the American Chemical Society, and by Doctor F. L. Miller, chairman of the subcommittee on chemistry of NRC. Doctor Miller referred to the highly interesting and profitable conferences of the past two years and acknowledged the real value that chemistry can contribute—and is contributing—to the solution of many complex problems in the use of dielectric materials. Doctor Miller thanked the American Chemical Society for its activity in sponsoring the symposium and for its valuable aid in bringing to the attention of chemists the varied and important problems on the chemical solution of which depends continued progress in the use of industrial dielectrics.

TECHNICAL SESSIONS

Liquid Dielectrics. J. D. Piper, in presenting the first paper, described a series of tests to determine which of the types of products that may be formed by the service degradation of insulating oils cause serious dielectric losses in oils at 60 cycles per second, and which do not. "Properties of systems composed of liquid paraffin and a cupric or lead soap of the following acids have been investigated: 1,10-hydroxystearic, stearic, palmitic, myristic, lauric, capric, pelargonic, caprylic, cyclohexanecarboxylic, undecylenic, erucic, and abietic acids. In the preparation of these soaps, some of which were crystalline, possible adsorption of alkali ions was avoided by treating the acetates with the above acids rather than with their alkali soaps.

"The systems containing cupric soaps of individual acids had low power factors and conductivities at all temperatures including those near which the soaps separated from solution. Systems containing mixed soaps, prepared from cupric abietate and certain acids or other soaps, however, had high power factors and high conductivities and dielectric constants at certain temperatures. . . . The dielectric properties of the systems are believed to be related to the state of dispersion of the soaps in the oil."

Insulating-Oil Deterioration. This paper, presented by J. L. Onclay, described investigations being conducted at Massachusetts Institute of Technology under the general direction of the committee on insulating oils and cable saturants of Utilities Co-ordinated Research, Inc. After an exhaustive presentation of the problem and its analysis, Doctor Onclay summarized the results as follows:

1. The relative proportions of various oxidation products and the rates of oxidation of hydrocarbons of various types vary over a rather large range.

2. The Grignard test is a very valuable tool, and reveals both the total oxidation products and the active hydrogen in an oil.

3. The synthetic hydrocarbons studied in this work had much lower dielectric losses for a given amount of chemical deterioration than did the group of oils studied.

4. Studies of the d-c conductivity, and of the power factor and dielectric constant over the frequency range from 40 to 400 cycles per second show that the dielectric losses are due almost entirely to ionic conduction.

5. Oils having an unusually large ratio of dielectric constant to density are usually found to exhibit a rapid rate of deterioration when subjected to oxidation.

6. Light transmission measurements over the entire visible portion of the spectrum are reported in the hope that such a study may reveal the nature of certain deterioration products.

7. The significance of volatile deterioration products is discussed from the viewpoint of their behavior in an oil-impregnated cable.

Mineral-Oil-Treated Insulation. Emphasizing that fundamental studies of insulating materials apart from the commercial product are of real value, Doctor Clark pointed out that such materials nevertheless are seldom used alone, and that the successful use of dielectrics in industrial service demands careful evaluation of the behavior of the composite assembly. Especially important are the deterioration products formed under high-voltage stresses in the presence of air at the higher operating temperatures, together with the dispersion of such products in—and on—the cellulosic insulation present. Doctor Clark's conclusions were summarized as follows:

1. The suitability of oil-treated cellulosic insulation for high-voltage application is determined

largely by the ability of the insulating mineral oil to resist the destructive effects of ionization and chemical oxidation.

2. The dielectric stability of mineral-oil-treated insulation is greatly influenced by the susceptibility of the mineral oil to oxidation. The beaker oxidation test, however, is not a proper gauge of the suitability of mineral oil for impregnation. Such tests fail to give data concerning the reactivity of the oxidation-formed products. The effect of high voltage stress on their formation and their ability to disperse through the cellulosic insulation and to be absorbed by it.

3. The ability of oil-treated cellulosic insulation to resist dangerous oxidation effects is best determined by an examination of the power factor of the treated paper as affected by a voltage life test. A suggested test is carried out at 75 degrees centigrade, the surface of the impregnating oil in which the test specimen is immersed being exposed to air.

4. To obtain the highest degree of dielectric stability in Gulf Coast mineral-oil-treated cellulosic insulation, the impregnating oil should contain a minimum of olefinic, unsaturated, oil-soluble compounds and a restricted amount of aromatic, unsaturated compounds of the type normally present in crude oil. For the Gulf Coast type of mineral oil the optimum amount of aromatic, unsaturated compounds should be between approximately four and five per cent.

5. Oil-soluble contaminants in the mineral oil may produce abnormally high initial power-factor values for the treated insulation. Equally dangerous effects are produced by those oil-soluble contaminants which have little effect on the initial power factor, but which contribute to insulation instability during the high-voltage use of the treated dielectric. Such a material is stearic acid.

6. Completely saturated paraffin hydrocarbon mixtures are not suitable for high-voltage dielectric use.

7. The addition of pure aromatic hydrocarbons of the benzenoid type to minerals in order to reduce gas evolution under electric discharge is limited by the effect of such materials on the dielectric stability of the treated insulation. Paraffinic carbon chains in the molecule of the aromatic addition must be avoided.

Electrical Application of Polystyrene. This paper, presented by L. A. Matheson, constituted an analysis of the properties of polystyrene. This substance, a transparent, thermoplastic solid, is formed by the polymerization of monomeric styrene, a colorless liquid having a boiling point of 146 degrees centigrade. Polystyrene has a low power factor (about 0.01 or 0.02 per cent) low water absorption, and low dielectric constant (from 2.6 to 2.8). "The low power factor and low water absorption seem to arise from the lack of polarity and the strong binding of all components in the chain. The polymer consists of only carbon and hydrogen atoms, the majority of which are in the benzene ring structures. Polystyrene is transparent and exhibits a tensile strength of from 5,000 to 7,000 pounds per square inch." It has a good modulus of elasticity and hardness and a fair impact strength. The maintenance of the impact strength at low temperatures is noteworthy. Operations which stretch the polymer during cooling are applied to increase the impact strength and the elongation before tensile break. Plasticizers may be added to increase the elongation and pliability.

The excellent dielectric properties and low water absorption promise a wide use for polystyrene in the electrical industry. Among the uses suggested for polystyrene are (1) cast pieces to be used where high resistance, transparency, and excellent electrical and mechanical properties are demanded; (2) high-voltage cable joints; (3) molded articles; and (4) films for cable and capacitor insulation.

The paper includes detailed data covering the properties of polystyrene; these are important in the proper application of the material for the uses suggested.

DINNER MEETING

Following the symposium was a "get together" dinner, at which F. M. Clark delivered an address on "A Chemical Approach to the Problem of High-Voltage Dielectrics."

As a result of the success of this symposium and its predecessors, the subcommittee on chemistry of NRC plans to schedule similar conferences each year under the auspices of other divisions of the American Chemical Society, in such fields as rubber, paint and varnish, cellulose, and plastics.

Membership—

Mr. Institute Member:

National and Section activities are now beginning for this season. You are urged to take full advantage of the many opportunities afforded you as a member to meet and join in discussions with your fellow engineers. Personal activity in these functions pays dividends.

Your membership committee is getting under way also. The assistance you have given the committee in the past has aided us greatly and is much appreciated. It is our hope that you will continue your fine co-operation.

With best wishes for a successful season.

L. L. Webb

Chairman, National Membership Committee

NRC Insulation Conference to Meet in Pittsburgh

The eleventh annual meeting of the conference on electrical insulation of the division of engineering and industrial research, National Research Council, will be held in Pittsburgh, Pa., November 3–4, 1938, where the conference will be the guests of the Westinghouse Electric and Manufacturing Company, the Gulf Research and Development Company, and the Mellon Institute of Industrial Research. Features of the meeting will comprise three technical sessions, a varied program of visits to many plants of scientific and industrial interest in the neighborhood, and the annual dinner of the conference.

In the technical sessions a program of unusual interest will be presented covering reports of recent progress in the scientific, the technical, and the practical aspects of dielectrics as applied to the problems of insulation. Progress reports will be presented from the National Bureau of Standards, several industrial research laboratories, and from a number of university laboratories. The tentative program, as at present arranged, comprises 24 papers. As is usual, the annual dinner on November 3, will be followed by a lecture. The speaker this year will be Doctor E. U. Condon, of the Westinghouse laboratories.

The headquarters for the meeting will be the Schenley Hotel. The chairman of the conference is Doctor J. B. Whitehead (A'00, F'12) of The Johns Hopkins University; the chairman of the local committee is Doctor C. F. Hill (M'29) of the Westinghouse Electric & Manufacturing Company.

Largest Generator Since 1931 Purchased. Niagara Hudson Power Corporation recently announced the purchase of the largest turbogenerator to be acquired by an electric utility company since 1931. The new equipment will be erected in a new station at Oswego, N. Y., construction of which is to be started soon by Central New York Power Corporation, a subsidiary of Niagara Hudson. Rated at 80,000 kw, 13,800 volts, 1,800 rpm, the generator will be cooled by hydrogen. The turbine, which will operate at an input steam pressure of 1,250 pounds per square inch and a temperature of 900 degrees Fahrenheit, exhausting into a vacuum of about one inch of mercury, is said to be the first high-pressure condensing unit to be built in a single casing. Length of the turbine will be slightly more than 53 feet over-all; its height above the floor is to be about 13 feet; and it will weigh approximately 500 tons. This unit is to be constructed by the General Electric Company, and is expected to be completed in about 14 months.

Electricity to Play Vital Role at the 1939 New York and San Francisco Fairs

ELECTRICITY will play a dominant role in the 1939 expositions of both East and West—the New York World's Fair to be held in New York City, and the Golden Gate International Exposition to be held in San Francisco, Calif. Not only will electricity be featured in special exhibit buildings at both fairs, but also it will play an almost indispensable part in staging the expositions and in lighting them. Special distribution systems are being constructed to supply the electric energy needed.

The New York fair will open April 30, 1939, the 150th anniversary of the inauguration of George Washington, which took place in New York City. It will be held on a site embracing 1,216 acres in Flushing Meadow Park situated in Queens, most easterly of the city's five boroughs. Its underlying theme is "building the world of tomorrow"; its estimated cost will be $150,000,000. After the fair is over, the site will be used as a city park and some of the buildings, of permanent construction, will remain.

The Golden Gate exposition commemorates the completion of San Francisco's two great bridges, the San Francisco-Oakland Bay Bridge and the Golden Gate Bridge; it will open February 18, 1939, and its estimated cost will be $50,000,000. The site of the exposition is a 400-acre man-made island in San Francisco Bay adjoining Yerba Buena Island and between the two bridges; there will be a highway connection with the bay bridge. After the fair is over, the island will be cleared of all buildings except the permanent administration building and two large hangars, and will become an airport.

Dominant structures in the New York fair will be a 200-foot "perisphere" and a 700-foot "trylon," both of which are interesting from an engineering point of view. The sphere will contain the theme exhibit of the fair, which will be observed from a moving platform around the inner periphery. The trylon is a slender triangular pyramid about 64 feet on a side at the base. A total of 6,710,000 pounds of steel comprising 7,125 pieces have been used in erecting the framework of these structures. Both will be covered with a white magnesite composition similar to stucco. As its dominating structure, the Golden Gate exposition will have its 400-foot Tower of the Sun. This tower will be topped by a 22-foot statue of a phoenix, covered with gold leaf.

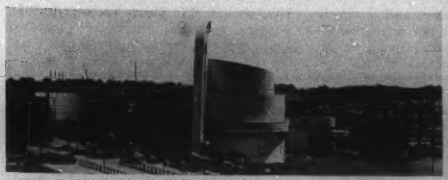
Electrical exhibits at the Golden Gate exposition will center in the Palace of Electricity and Communication, while the New York fair will have its Electrical Building and private exhibit buildings to be erected by electrical manufacturers and utilities. Communications exhibits will be housed in a separate building at the New York fair and in buildings to be erected by some of the major communication systems. Electrical exhibits at both fairs will emphasize the contributions of electricity to modern living and will attempt to predict how electricity may contribute in the future. Both fairs will have "electric farms." Of particular interest among the exhibits at the New York fair will be a lightning laboratory capable of producing 30-foot arcs which may be observed by visitors. Among the interesting communication features at the Golden Gate fair will be a radiobroadcasting center. Both fairs will have television demonstrations.

Perhaps electricity's greatest contribution to both fairs will be the provision of illumination. Of particular significance is the fact that both expositions will be considered as co-ordinated units from the standpoint of both color and illumination. Electrical illumination of all types will "paint" the fairs at night. Of especial interest will be the wide application of fluorescent lighting to be provided chiefly by the new gaseous tube fluorescent lamps (*EE, June '38, p. 245–8; July '38, p. 286–90*). At the San Francisco fair fluorescent paint will be used on some of the murals which will be activated by ultraviolet radiation or so-called "black light" (*EE, Dec.' 37, p. 1449*). At the New York fair, trees in some of the areas will be irradiated with ultraviolet radiation, which will cause the leaves to fluoresce. Luminaires of unique designs will be found in abundance at both expositions. Interior illumination also will be unique.

In addition to the strictly electrical displays and the illumination, many other exhibits will be of interest to electrical engineers, particularly the transportation, science, and chemical exhibits. All types of transportation will be featured, and at the New York fair the building erected by the Eastern Railway Presidents Conference will be the largest on the grounds. San Francisco will have a special demonstration featuring electricity in business, and a model cyclotron or "atom smasher" designed to produce radioactive emanations for the treatment of cancer and other diseases.

Among the spectacular displays of special interest at the fairs will be a reproduction of the geyser "Old Faithful" at San Francisco, which will erupt regularly with a 150-foot column of water illuminated at

A recent view of the New York World's Fair showing most of the exhibit area, taken on the day that the final rivet was driven in the theme-center structures. Part of the electrical building may be seen at the extreme right edge



Electrical building at the New York World's Fair. The building of the Consolidated Edison Company of New York, Inc., may be seen at the left and the steel frame of the Westinghouse Electric and Manufacturing Company building at the right

(Right) A recent view of the Golden Gate International Exposition showing the main entrance and part of the grounds. The electrical building is immediately to the left of the main entrance

night, and two "super" fountains at the New York fair. One of these displays will include water and flame synchronized with color effects and special music and sound. The other display, which is described as "the nearest approach to chaos that man can contrive for purposes of sheer entertainment," will combine all these elements and will include fireworks as well.

To provide the electric energy needed for the fairs, special distribution systems are being built. San Francisco will have a 16,000-kva substation supplied from the Oakland side of the bay over three submarine cables 9,000-feet long. Power will be distributed to various parts of the island by means of 4,000-volt underground feeders. New York's $2,000,000 distribution system will comprise two 45,000-kva substations fed by 27-kv feeders. Each substation will be supplied from two sources over different routes. Power will be distributed from these substations to various parts of the grounds by means of 4,150-volt feeders.

Of particular interest to those members who may plan to visit the Golden Gate exposition is the fact that the AIEE will hold a combined summer and Pacific Coast convention in San Francisco, June 26–30, 1939.

Transactions Supplement for 1938 to Be Issued

To enable members and subscribers to receive a complete file of the technical papers and related discussions not published in the TRANSACTIONS section of ELECTRICAL ENGINEERING under the present publication policy during 1938, a special "TRANSACTIONS Supplement" will be published in December, as announced in a special brochure recently mailed to all AIEE members. This supplement together with the 12 issues of ELECTRICAL ENGINEERING will provide *all* the technical papers and discussions published by the Institute during the year.

Normally under the present publication policy, the TRANSACTIONS Supplement would contain approximately 350 pages reprinted from the TRANSACTIONS, and the price to members would be $1.00 per copy postpaid. Because of the effects of this year's transition in publication procedure, however, the 1938 Supplement will contain only some 85 pages and will be available to members at 50¢ per copy postpaid. The Supplement will be paper bound similar to ELECTRICAL ENGINEERING.

Advance orders are required because the number of copies to be printed will be determined by the demand. Therefore, those wishing to receive copies should fill in the appropriate spaces on the return card accompanying the mailed announcement (or use the order form on page 18 of the advertising section of this issue) and forward it at once to AIEE Headquarters, 33 West 39th Street, New York, N. Y.

Industrial Research Institute Formed

The Industrial Research Institute, an organization of research executives affiliated principally with middle-sized and small industrial corporations, has been formed following a series of preliminary meetings at New York, N. Y., according to an announcement by Maurice Holland (A'23, M'30) director of National Research Council's division of engineering and industrial research, who is acting as executive officer of the new group.

Research men in various fields of industry had expressed a desire for an organization in which they could discuss laboratory organization and administration and other problems common to directors of scientific research. Representatives of 40 industrial corporations attended the first preliminary meeting in March 1938 when results of a survey among 500 research laboratories to determine the extent of the need of the organization were reported.

The executive committee of the new body will serve as a committee of NRC during the formative and development stages. R. P. Colgate, vice-president, Colgate-Palmolive-Peet Company, has been named chairman, and H. W. Graham, general metallurgist, Jones and Laughlin Steel Corporation, is vice-chairman. The NRC division of engineering and industrial research has made its facilities and technical resources available to the new research institute during the organization period; present headquarters are at the offices of the NRC division at 29 West 39th Street, New York, N. Y.

ICI Sessions in Holland. The next sessions of the International Commission on Illumination will be held in Holland June 12–21, 1939, according to advice just received from the Central Bureau in England. The meeting will be at Scheveningen, the seashore resort and suburb of The Hague where the International Electrotechnical Commission met in 1935.

17-Year AIEE Index Now Under Consideration

The issuance of a cumulative index to its technical papers for the 17-year period, 1922–38, currently is under consideration by the Institute, as announced in a special brochure recently mailed to all AIEE members. Such a volume would complete the series of indexes covering Institute papers from 1884 to date, but will be issued only if there is sufficient demand for it. As an added inducement, it is planned that a copy of the previous index volume, covering the years 1911–21, will be given free of charge to those ordering copies of the new index, until the present stock is exhausted.

Covering some 2,500 reports and technical papers by several hundred authors and technical committees, the proposed index would comprise a volume of 150 or more $8^1/_2$- by 11-inch pages containing some 15,000 reference entries alphabetically arranged. The style and arrangement of the index would be similar to the annual multi-entry indexes that have been published during recent years for TRANSACTIONS and ELECTRICAL ENGINEERING.

Although the project has been approved in principle by the board of directors, upon recommendation of the publication committee, budget provision will be made only if it receives sufficient support among Institute members and subscribers to Institute publications. The price of the proposed 17-year index to AIEE members will range from $1.25 upward, depending upon the quantity to be produced, but will be kept to a minimum. Those interested are

urged to fill in the appropriate spaces on the return card accompanying the mailed announcement (or use the order form on page 18 of the advertising section of this issue) and forward it at once to AIEE Headquarters, 33 West 39th Street, New York, N. Y.

Institute Publication Buried in Time Capsule

The seven-foot "time capsule," recently deposited 50 feet in the earth beneath the exhibit building of the Westinghouse Electric and Manufacturing Company on the grounds of the New York World's Fair 1939, contains a complete copy of the Institute's 50th anniversary (May 1934) issue of ELECTRICAL ENGINEERING reproduced on microfilm. The 800-pound "cupaloy" metal envelope is addressed to people living 5,000 years hence, and is intended to preserve for scientists of the year 6939 a tangible record of life in the present era. It contains representative fruits of the modern achievements in science and art, delineated by such things as news reels and

The time capsule itself is made of two parts: an inner "crypt" of heat-resistant glass surrounded by a corrosion-resisting copper-alloy shell

books reproduced on microfilm and selected subjects from laboratories, factories, and cities.

A single copy of the May 1934 issue of ELECTRICAL ENGINEERING is twelve inches long, nine inches wide, and about three-quarters inch thick. This represents a volume of 81 cubic inches, and obviously the time capsule could not accommodate enough of such books to provide an accurate literary cross section of this age. This was one reason for the use of microfilm in reproducing the buried documents. An entire book may be reproduced on a roll of microfilm that occupies a volume of only three or four cubic inches. But there was another reason; the material of which film base is made has been found to be more resistant to the ravages of time than even the finest of rag papers.

Egyptians had an excellent way of preserving mummies, and modern scientists always have been a little curious about how it was done. Assuming that the time capsule actually is found intact by some savant of the nebulous year 6939, he probably will marvel at the remarkable durability of the metallic shell surrounding the buried treasure. But Westinghouse engineers are not going to frustrate his curiosity as Egyptians have frustrated scientists of our day, for the time capsule contains the formula for the metallic material known as "cupaloy," an alloy of copper, chromium, and silver, of which the shell is made.

This metal is believed to have the physical and chemical durability necessary to insure its survival against the corroding action of sea water in the soil of the World's Fair grounds during the next five milleniums. Copper itself is resistant to corrosion of salt water, because the products of initial corrosion accumulate and protect the underlying metal. The presence of chromium in the alloy probably will increase the protective value of the film which would be expected to form under the influence of undisturbed soil corrosion. Confidence in the ability of the alloy to withstand the attack of time is strengthened by the evidence of many copper implements that have been preserved from antiquity. A further reason for the belief in the ability of the capsule to withstand corrosion is that in electrolytic reactions with corrosive salts, such as iron salts, copper becomes the positive electrode and therefore receives deposits instead of being eaten away in the process.

Inside the metallic shell of the capsule is a six-foot chamber made of heat-resistant glass, which contains the items representing a "cross section" of our time. This glass envelope was evacuated and filled with an inert gas to act as a preservative, then wrapped with glass tape and embedded in a waterproof compound.

Simultaneously with the deposit of the capsule, the leading libraries, museums, and repositories of the world will receive a finely bound and printed book, published on the most permanent paper, telling future archaeologists where the capsule lies, what is in it, and how to locate and recover it.

IES Elects Officers. During the 32d annual convention of the Illuminating Engineering Society, Milwaukee, Wis., August 29–September 1, 1938, the following new officers were elected: *president*, D. W. Atwater (A'34), Westinghouse Lamp Division, Bloomfield, N. J.; *vice-president* (term expires 1939), L. H. Grades, Curtis Lighting, Inc., New York, N. Y.; *vice-president* (term expires 1940), A. D. Cameron, Holophane Company, Inc., New York, N. Y.; *general secretary*, H. M. Sharp (M'34), Buffalo, Niagara, and Eastern Power Company, Buffalo, N. Y.; *treasurer*, H. G. Clum, Jersey Central Power and Light Company, Asbury Park, N. J. The 1939 annual convention of the society is scheduled to be held at San Francisco, Calif.

"Dams and Control Works," revised edition of a book first published in 1929, has been announced by the United States Bureau of Reclamation. Dams of various types, control works, and special engineering investigations of the bureau are described in detail; chapters are devoted to the design and construction of such outstanding structures as Boulder and Grand Coulee Dams, and special articles discuss such subjects as high-pressure reservoir outlets and temperature control of mass concrete in large dams. A tabular description of 138 dams built by the bureau and a general map of federal irrigation projects are included. The book may be obtained from the Bureau of Reclamation, Washington, D. C., at $1 a copy.

Future Meetings of Other Societies

American Association for the Advancement of Science. Winter meeting, December 27–31, Richmond, Va.

American Gas Association. October 10–14, Atlantic City, N. J.

American Institute of Mining and Metallurgical Engineers. Coal division (joint meeting with ASME and Western Society of Engineers), October 13–15, Chicago, Ill.

Industrial minerals division, October 20–21, Los Angeles, Calif.

American Physical Society. 223d meeting, November 25–26, Chicago, Ill.

224th meeting, December 1938, Los Angeles, Calif.

Annual meeting, December 26–28, Washington, D. C.

American Society of Civil Engineers. Fall meeting, October 12–14, Rochester, N. Y.

Annual meeting, January 18–20, New York, N. Y.

American Society of Heating and Ventilating Engineers. 1939 annual meeting, January 23–26, Pittsburgh, Pa.

American Society of Mechanical Engineers. Joint meeting with AWS, October 18, Detroit, Mich.

Annual meeting, December 5–9, New York, N. Y.

American Welding Society. 19th annual meeting and welding exposition, October 16–21, Detroit, Mich.

National Electrical Manufacturers Association. October 24–28, Chicago, Ill.

National Metal Congress. October 17–20, Detroit, Mich.

National Research Council, Highway Research Board. 18th annual meeting, November 30–December 2, Washington, D. C.

Society of Automotive Engineers. National transportation engineering meeting, November 14–16, New York, N. Y.

Annual meeting, January 9–13, Detroit, Mich.

Letters to the Editor

CONTRIBUTIONS to these columns are invited from Institute members and subscribers. They should be concise and may deal with technical papers, articles published in previous issues, or other subjects of some general interest and professional importance. ELECTRICAL ENGINEERING will endeavor to publish as many letters as possible, but of necessity reserves the right to publish them in whole or in part, or reject them entirely.

ALL letters submitted for consideration should be the original typewritten copy, double spaced. Any illustrations submitted should be in duplicate, one copy to be an inked drawing but without lettering, and other to be lettered. Captions should be furnished for all illustrations.

STATEMENTS in these letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the American Institute of Electrical Engineers.

Symmetrical-Component Impedance Notation

To the Editor:

No entirely adequate and consistent notation for impedances in symmetrical components has been presented in the books on symmetrical components nor has such a notation come into general use. In particular, the symbols Z_0, Z_1, Z_2 have been used with two entirely different meanings (as described in this letter) which cannot but lead to confusion. I advocate the adoption of the simple, logical, and easily remembered double-subscript notation employed in the following equations:

$$\begin{aligned} V_0 &= Z_{00}I_0 + Z_{01}I_1 + Z_{02}I_2 \\ V_1 &= Z_{10}I_0 + Z_{11}I_1 + Z_{12}I_2 \\ V_2 &= Z_{20}I_0 + Z_{21}I_1 + Z_{22}I_2 \end{aligned} \qquad (1)$$

where V = voltage drops across any branch of a three-phase circuit, I = currents in the branch, and Z = impedances of the branch; subscripts 0, 1, 2 denote zero, positive, and negative phase sequence.

The analogous equations in phase quantities are as follows:

$$\begin{aligned} V_a &= Z_{aa}I_a + Z_{ab}I_b + Z_{ac}I_c \\ V_b &= Z_{ba}I_a + Z_{bb}I_b + Z_{bc}I_c \\ V_c &= Z_{ca}I_a + Z_{cb}I_b + Z_{cc}I_c \end{aligned} \qquad (2)$$

where subscripts a, b, c denote the phases.

In both sets of equations the symbol Z for impedance has two subscripts, one referring to voltage and the other to current. The two subscripts of self-impedances are alike; those of mutual impedances are unlike. The order of the subscripts of a mutual impedance is significant, because the mutual impedance between phases or between sequences may be nonreciprocal, that is, it may have unequal values in the two directions. The order of subscripts is easy to remember, because the first subscript of impedance is like that of the voltage, which is written ahead of the impedance symbol; and the second subscript is like that of the current, which is written after the impedance symbol.

The meaning of the impedance symbols is apparent from the equations. For example, Z_{ab} is the ratio of the voltage across phase a to the current in phase b when there is no current in phases a and c; Z_{ba} is the ratio of the voltage across phase b to the current in phase a when there is no current in phases b and c. Impedances Z_{ab} and Z_{ba} are unequal if, for example, a and b are the stator windings of an induction machine having closed moving rotor circuits. Z_{12} is the ratio of positive-sequence voltage to the negative-sequence current when there is no positive- nor zero-sequence current; and so forth.

Each symmetrical-component impedance in equations 1 is a function of the nine phase impedances of equations 2, as indicated by the following table:

	Z_{aa}	Z_{bb}	Z_{cc}	Z_{bc}	Z_{ca}	Z_{ab}	Z_{cb}	Z_{ac}	Z_{ba}
Z_{00}	1	1	1	1	1	1	1	1	1
Z_{01}	1	a^2	a	a	1	a^2	a^2	a	1
Z_{02}	1	a	a^2	a^2	1	a	a	a^2	1
Z_{10} 1	1	a	a^2	a	a^2	1	a^2	1	a
Z_{11} –	1	1	1	a^2	a^2	a^2	a	a	a
Z_{12} 3	1	a^2	a	1	a^2	a	1	a^2	a
Z_{20}	1	a^2	a	a^2	a	1	a	1	a^2
Z_{21}	1	a	a^2	1	a	a^2	1	a	a^2
Z_{22}	1	1	1	a	a	a	a^2	a^2	a^2

(3)

which is to be interpreted thus:

$$Z_{01} = \frac{1}{3}(Z_{aa} + a^2Z_{bb} + aZ_{cc} + aZ_{bc} + \ldots),$$

etc.

where $a = \underline{/120°}$

The method of symmetrical components does not present any advantage over the use of phase quantities unless equations 1 are simpler than equations 2. The increased simplicity might lie in having reciprocal mutual impedances in equations 1 for nonreciprocal impedances in equations 2, or in having the mutual impedances in equations 1 vanish when those in equations 2 do not.

The conditions for which the inter-sequence impendances are reciprocal, that is, for which

$$Z_{01} = Z_{10}, \qquad Z_{02} = Z_{20}, \qquad Z_{12} = Z_{21}$$

is readily shown to be that

$$Z_{bb} = Z_{cc}, \quad Z_{ca} = Z_{ab}, \quad Z_{ac} = Z_{ba} \qquad (4)$$

These conditions may be termed "symmetry with respect to phase a."

The conditions for which the inter-sequence impedances vanish are that

$$Z_{aa} = Z_{bb} = Z_{cc}, \quad Z_{bc} = Z_{ca} = Z_{ab}, \text{ and } Z_{cb} = Z_{ac} = Z_{ba} \qquad (5)$$

These conditions may be called "balanced impedances."

With balanced phase impedances in equations 2, the only impedances in equations 1 that are not zero are the self-impedances Z_{00}, Z_{11}, and Z_{22}. Under these conditions the simpler notation Z_0, Z_1, Z_2, which is widely used, seems appropriate.

Another interesting special case is that in which the mutual impedances between phases are zero and the phase self-impedances are unequal. In this case,

$$Z_{00} = Z_{11} = Z_{22} = \frac{1}{3}(Z_{aa} + Z_{bb} + Z_{cc})$$

$$Z_{02} = Z_{10} = Z_{21} = \frac{1}{3}(Z_{aa} + aZ_{bb} + a^2Z_{cc})$$

$$Z_{01} = Z_{12} = Z_{20} = \frac{1}{3}(Z_{aa} + a^2Z_{bb} + aZ_{cc})$$

There are in this case only three different values of impedance in equations 1, but each one appears there three times. These three values sometimes are designated Z_0, Z_1, Z_2; and the so-called "sequence rule" is used, by which the sequence of a ZI drop is given by the sum of the subscripts of Z and I, for example,

$V_2 = Z_2I_0 + Z_1I_1 + Z_0I_2$, etc.

The notation Z_0, Z_1, Z_2 with this significance is not recommended because of confusion with the more usual significance, Z_{00}, Z_{11}, Z_{22}, for balanced phase impedances. The subscripts in this notation are the difference between the two subscripts in the recommended double-subscript notation.

In conclusion, the double-subscript notation of equations 1 is recommended for universal use, except that Z_0, Z_1, Z_2 may be used with their common meaning, as being equivalent to Z_{00}, Z_{11}, and Z_{22}, respectively with the added implication that the inter-sequence mutual impedances are negligible. The conditions of the phase impedances for which the inter-sequence mutual impedances vanish, and for which they are reciprocal, have been stated in equations 5 and 4, respectively.

Very truly yours,

EDWARD W. KIMBARK (A'27, M'35)

(Professor of Electrical Engineering, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.)

Engineers and Social Problems

To the Editor:

Doctor Jewett's discussion of "The Engineer and Trends in Economic Thought" is most interesting; especially his characterization of the claims that the revival of ancient fallacies are scientific experiments. It would be just as legitimate and logical to attempt to disprove the rule of three, under the pretense of scientific experimentation, as to attempt to justify some of the present day economic and even engineering delusions under the same pretense.

I do wish, however, that Doctor Jewett had been a little more specific and concrete in stating exactly what engineers can and should do to dispel the hallucinations which seem to affect, or afflict, so much economic thought and even accounting practice that classifies liabilities as assets.

It is true that engineers have a responsibility in these matters, but it is likewise true that they have been remiss in the assumption and performance of this duty. An outstanding example of remissness is the refusal even to permit consideration of the suggestion that the Institute membership be polled on the proposition to investigate what Doctor Vannevar Bush so aptly characterized as a "fool piece of work in any language." The important issue, therefore, is not the engineers' responsibilities in the abstract, but their assumption of these responsibilities in the concrete.

Doctor Jewett again calls attention to the relation of science to the economic well-being of the people, and in partial justification of the adverse criticisms of science he cites some moral delinquencies of the present age. If, as the critics assume, scientific discoveries and inventions cause a decay of moral fiber, the mechanistic concept of life is proved, and the amelioration of social maladjustments can be achieved only by a change in environment. I doubt, however, the validity of such a conclusion. The motor car is not the cause of crime. It is merely an agency that facilitates criminal activities. Criminals always have used, and always will use, every facility available. Although it is true that standards of right and wrong change, nevertheless it is also true that an act that was wrong in the horse-and-buggy days does not become right by a mere change in vehicles. Neither the agency nor the surroundings have anything to do with the morality of the deed.

In most of the discussions of the relative mentality and intellectual achievements of men of the present and of past ages, it is tacitly assumed that the outstanding few of ancient times were typical of all. That assumption is disclosed in the extract from an article by Sir Gilbert Murray cited by Doctor Jewett. The fact is, however, that Millet's "Man with the Hoe" is just as typical of the ancient Chaldeans as Sir Gilbert Murray's "stupid fat man driving fast in a beautiful motor car," is of the present day. Stupid men are not exclusively the product of any particular age.

That the Chaldean astronomer was a man of high intellectual power, no intelligent man will deny, but in contrast astronomers of the present day, such as Sir James Jeans, are no weaklings.

In a comparatively recent address Sir James completely answers Sir Gilbert's gloomy forebodings:

> "Unhappily, no amount of planning can arrange a perfect balance. For as the wind bloweth where it listeth, so no one can control the direction in which science will advance; the investigator in pure science does not know himself whether his researches will result in a mere labor saving device or a new industry. He only knows that if all science were throttled down, neither would result; the community would become crystallized in its present state, with nothing to do but watch its population increase, and shiver as it waited for famine, pestilence, or war which must inevitably come to restore the balance between food and mouths, land and populations.
>
> "Is it not better to press on in our efforts to secure more wealth and leisure and dignity of life for our own and future generations, even though we risk a glorious failure, rather than accept inglorious failure by perpetuating our present conditions, in which these advantages are the exception rather than the rule? Shall we not risk the fate of that over-ambitious scientist, Icarus, rather than resign ourselves, without effort, to the fate which has overtaken the bees and ants? Such are the questions I would put to those who maintain that science is harmful to the race."

The affirmation of Sir James that science like the wind "bloweth where it listeth" is also a most cogent answer to Doctor Jewett's assumption that "we have failed to take seriously enough the matter of foreseeing and providing for the more important social consequences of our material achievements."

The fundamental fallacy of social and economic planners is the assumption that some persons possess the necessary omniscience to "foresee and provide for the consequences of our material achievements"; in short, that economic and social planning is possible.

Nevertheless, there are times when one is almost persuaded to agree with the critics of scientists and inventors. For example, when a popular writer of social and economic subjects asserts: "It would be a jolly good thing to declare a moratorium on inventions for at least a decade, and treat all inventors as dangerous lunatics with proper care and supervision," one is inclined to agree; for if the typewriter, typesetting, and electrotyping processes had never been invented there would be very limited circulation of such stark-staring stultiloquy.

Again, when an economist says that "the problem of the modern age is to adjust itself to the new monster, the machine," one is inclined to say, "it would be a jolly good thing" if some one invented an "oxometer" that would automatically delete such nonsense. Even this letter would be shorter if it were run through such a device.

Another dominant fallacy is the mistaken notion that money is wealth. This fallacy permeates the thinking processes of even some outstanding scientists, one of whom in a commencement address said:

> "The blind faith in causation is the main source of most of the heated discussions on economic questions. A prominent editorial writer of one of our leading newspapers was led recently to vigorous denunciation of the plowing under of the cotton crop because he believed 'that the destruction of wealth cannot produce wealth.' He refers to this as though it were some great natural law. But where has such a law been proved? It appears, of course, an absurdity to produce wealth by destroying it, but we live in an absurd world in which the population has the capacity and the ability to produce enough commodities to sustain a high standard of living, yet because of unemployment there does not exist the purchasing power to permit its realization. Surely there is no natural law which proves that the destruction of a certain fraction of our wheat supply could not raise the total value of the remaining wheat sufficiently to offset the loss involved."

The proof of the accuracy of the editor's affirmation is found in a mythical fable of the sale of three books for the price originally asked for nine by the sibyl of Cumae to Tarquinius Superbus. The emperor paid the price, but he got only three books after six were destroyed.

It is entirely proper and fitting that men of the scientific standing of Doctor Jewett contribute their thoughts to the eradication of absurdities and pernicious practices. It must not be forgotten, however, that man in the future as in the past will use the discoveries of science as he sees fit without regard to the advice and foresight of the engineer. The greatest contribution that engineers and scientists can make to society is to maintain their intellectual and moral integrities, which is the great present-day disederatum. This in itself will do much "to offset the superficial assumptions engendered by outward appearances," and "will impel men and women to seek advice from those who have it and to ponder this advice before acting." But before this consummation can be realized, the engineer must give his advice unsought.

Very truly yours,

C. M. JANSKY (A'06, F'32)
(Professor of Electrical Engineering, University of Wisconsin, Madison)

Sharp Cutoff in Vacuum Tubes

To the Editor:

In a recent paper[1] the theoretical expression for the current of a high-vacuum diode is given as

$$I = I_s \exp(-eV/kT) \qquad (1)$$

for low anode current and negative anode voltage, where I is the anode current, V the negative anode voltage, I_s the saturation current, T the absolute temperature of the emitter, e the charge of an electron, and k Boltzmann's constant. This equation was taken from a book by A. Hund.[2]

The expression for the diode current with a negative anode voltage for concentric cylindrical electrodes, a common commercial arrangement, was derived by Schottky[3] and given as

$$I = I_s \frac{2}{\sqrt{\pi}} \left\{ \sqrt{\frac{eV}{kT}} \exp\left(\frac{eV}{-kT}\right) + \int_{\sqrt{\frac{eV}{kT}}}^{\infty} \exp(-x^2)dx \right\} \qquad (2)$$

It was pointed out by Schottky, and more completely by Davisson,[4] that this equation fails for $V = 0$ (since the current would then be the saturation current which is obtained only with relatively high anode voltages); fails for values of V which permit a space charge potential minimum between anode and cathode; and may fail even for values of V which do not permit a voltage minimum. It was shown by Germer[5] that the Schottky equation holds at large negative values of anode voltages.

The assumption made in using equation 1 was either that the electrodes were infinite parallel planes,[6] or that equation 2 reduces to the form of equation 1 for large values of V. The latter would obtain only if the second (probability) term is small and

$$\frac{2}{\sqrt{\pi}} \sqrt{\frac{Ve}{kT}} \approx 1$$

Both of these conditions cannot simultaneously exist, for the probability term is comparatively small only at very high anode voltages, and the second condition requires $V = 0.0678$ volts for $T = 1{,}000$ degrees Kelvin.

It is interesting to note, however, that an empirical equation of the form

$$I = A \exp(-BV) \qquad (3)$$

where A and B are constants, holds over a limited range of negative anode voltage. Figure 1 shows curves of anode current plotted against voltage obtained from data on commercial tubes. It may be seen that equation 3 holds approximately for the type 5T4 which has a filamentary cathode, the type 59 tube which has two heater cathodes with unipotential surfaces and several

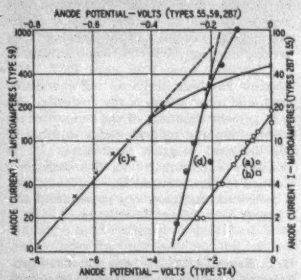


Figure 1. Curves of anode current versus negative anode voltage for commercial tubes

(a) Type 55 tube, diode section only; heater type

(b) Type 2B7 tube, diode section only; heater type

(c) Type 59 tube, pentode with grids and plate interconnected; heater type

(d) Type 5T4 tube, rectifier filamentary type with center tap of transformer used as cathode

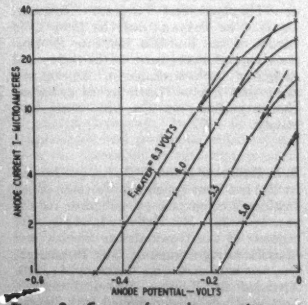


Figure 2. Curves of anode current versus negative anode voltage of 1-V tube for different heater voltages

grids, and for the types 2B7 and 55, which were used as diodes.

In figure 2 are plotted curves of anode current against voltage of a 1-V tube for various heater voltages. Equation 1 would predict lines of strikingly different slopes and would not apply to a cylindrical unipotential cathode tube like the 1-V. The curves are similar to those obtained by Germer, in his check of Schottky's equation.

It should be pointed out that the deductions in the paper by Aiken and Birdsall[1] are not affected by these comments, for, as seen from their equation 4, the term I_s is absorbed in a constant G which is adjustable by means of grid-voltage change.

Yours truly,

G. H. Fett (A'32)

(Department of Electrical Engineering, University of Illinois, Urbana)

References

1. Sharp Cutoff in Vacuum Tubes, With Applications to the Slideback Voltmeter, **C. B. Aiken** and **L. C. Birdsall**. AIEE Transactions, volume 57, 1938 (April section) pages 171–6.

2. Phenomena in High-Frequency Systems, **A. Hund**, (a book). McGraw-Hill Book Company, page 7.

3. **W. Schottky**, *Annalen der Physik*, volume 44, 1914, page 1011.

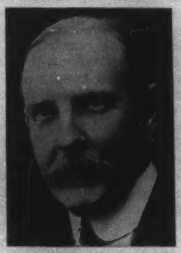
4. **C. Davisson**, *Physical Review*, volume 25, 1925, page 808.

5. **L. H. Germer**, *Physical Review*, volume 25, 1925, page 795.

6. **I. Langmuir**, *Physical Review*, volume 21, 1923, page 419.

Personal Items

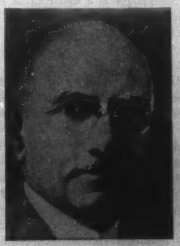
A. E. Kennelly (A'88, F'13, HM'33, Edison Medalist '33, past-president) has been elected honorary president of the International Electrotechnical Commission. Doctor Kennelly, who is professor emeritus of electrical engineering at Harvard University and Massachusetts Institute of Technology, was born near Bombay, India, December 17, 1861, and received his early education in private schools in Europe. He



A. E. KENNELLY

was awarded the honorary degree of doctor of science by the University of Pittsburgh in 1895, and by the University of Toulouse, France, in 1922, and received the honorary degree of master of arts from Harvard University in 1906. In 1875 he became assistant secretary of the Institution of Electrical Engineers (Great Britain). After holding various other positions he came to the United States in 1887, and was engaged as principal electrical assistant to Thomas A. Edison until 1894. In that year he became associated with Edwin J. Houston in the firm of Houston and Kennelly. Doctor Kennelly was appointed professor of electrical engineering at Harvard University in 1902, and continued in that position until he retired from active service in 1930. From 1913 until 1924 he was professor of electrical engineering at Massachusetts Institute of Technology, and for some years was director of electrical engineering research and chairman of the faculty of that institution. Doctor Kennelly has been honored by many scientific societies for his achievements. He served as a United States delegate to the international electrical congresses in Paris (1900) and St. Louis (1904) and the international radio conferences in Paris (1921) and Washington (1927). He is also honorary president of the United States National Committee of the International Electrotechnical Commission.

D. C. Jackson (A'87, F'12, past-president) has been appointed chairman of the Institute's committee on code of principles of professional conduct. Born at Kennett Square, Pa., Doctor Jackson received the degrees of bachelor of science and civil engineer from Pennsylvania State College, subsequently pursuing postgraduate study in electrical engineering at Cornell University for two years. He was awarded the honor-



D. C. JACKSON

ary degree of doctor of science by Columbia University. From 1887 until 1889 he was vice-president and engineer for the Western Engineering Company, Lincoln, Nebr. In the latter year he became assistant chief engineer with the Sprague Electric Railway and Motor Company, New York, N. Y., and in the following year became chief engineer for the Edison General Electric Company. In 1891 he formed a consulting engineering firm with W. B. Jackson and became professor of electrical engineering at the University of Wisconsin. In 1907 he became professor and head of the department of electrical engineering at Massachusetts Institute of Technology. Doctor Jackson formed a partnership with E. L. Moreland (A'11, F'21) in 1919 and was senior partner in the firm until 1930. In 1935 he retired

from active service at Massachusetts Institute of Technology and became professor emeritus of electrical engineering. Doctor Jackson was a vice-president of the Institute from 1897 until 1899 and was president during 1910–11. He has been a member of the committee on code of principles of professional conduct since 1936, and at various times has been member or chairman of many of the Institute's other committees. At present Doctor Jackson is a member of the committee on legislation affecting the engineering profession and the committee on standards.

R. W. Sorensen (A'07, F'13, director, past vice-president) has been appointed chairman of the Institute's committee on student branches for the year 1938–39. At present professor and head of the department of electrical engineering at California Institute of Technology, Pasadena, Calif., Doctor Sorensen was born at Alta Vista, Kans., April 25, 1882, and received the degrees of bachelor of science in electrical engineering (1905) and electrical engineer (1928) from the University of Colorado. The same school awarded him the honorary degree of doctor of science recently. He was employed by the General Electric Company at Schenectady, N. Y., and Pittsfield, Mass., from 1905 until 1910, when he was appointed associate professor of electrical engineering at Throop Polytechnic Institute, which later became California Institute of Technology. He was appointed professor during the following year. From 1933 until 1935 Doctor Sorensen was a vice-president of the Institute. At various times he has served as member or chairman of many of the Institute's technical and general committees, and currently is a member of the Edison Medal committee and the committee on economic status of the engineer.

K. B. McEachron (A'14, F'37, director) has been appointed chairman of the Institute's committee on protective devices for the year 1938–39. Doctor McEachron is director of high-voltage research at the Pittsfield (Mass.) works of the General Electric Company. He was born at Hoosick Falls, N. Y., November 17, 1889, and was graduated from the electrical-engineering course at Ohio Northern University in 1913. Recently he received the honorary degree of doctor of engineering from the same institution. Following his graduation in 1913 he was employed as a test engineer for the General Electric Company at Pittsfield, and during the next four years was an instructor in electrical engineering at Ohio Northern. From 1918 until 1922 he was a member of the staff of Purdue University, acting as instructor in electrical engineering and as research associate in the engineering experiment station. He received the degree of master of science in electrical engineering there in 1920. In 1922 Doctor McEachron returned to the General Electric Company at Pittsfield, and in 1933 was appointed to his present position. Currently a director of the Institute, Doctor McEachron has been a member of the committee on protective devices since 1933, and is a member of the committee on basic sciences also.

P. O. Crawford (A'09, M'25) has resigned as president of American Utilities Service Corporation, Savannah, Ill., to become operating vice-president of Central Service Corporation, Chicago, Ill. A native (1885) of Malvern, Ohio, Mr. Crawford attended The Ohio State University, and was graduated from Stanford University with the degree of bachelor of arts in electrical engineering in 1908. Following his graduation he became a construction engineer for the Northern California Power Company and remained there until 1912. In that year he became assistant chief engineer on the design and construction of a hydroelectric system in Kabul, Afghanistan. In 1915 Mr. Crawford returned to Stanford University to pursue research in high-voltage engineering and one year later he became associated with the California-Oregon Power Company, eventually becoming chief engineer (1920) and vice-president and chief engineer (1923). From 1929 until 1924 he was successively president, receiver, and trustee of the Federal Public Service Corporation, and upon reorganization of that corporation in 1934 he became president of American Utilities Service Corporation, the new company.

L. W. W. Morrow (A'13, F'25, past director) has been appointed chairman of the Institute's Edison Medal committee for the year 1938–39. Mr. Morrow is a native (1888) of Hammond, W. Va., and was graduated from Marshall College in 1907 and Cornell University in 1911. During the scholastic year following his graduation in 1911 he served as an instructor at Cornell University, and in 1913 was appointed assistant professor of electrical engineering at the University of Oklahoma. During the year 1917–18 he was professor of electrical engineering and director of the school of electrical engineering, before becoming assistant director of the United States Signal Corps school at Yale University. He served concurrently as an assistant professor of electrical engineering on the faculty at Yale, and following the World War was retained in that position. In 1922 Mr. Morrow became associate editor of *Electrical World;* in 1929 he became editor of that publication, but resigned in 1936 to become manager of the fiber products division of the Corning Glass Works, Corning, N. Y. He was a director of the Institute from 1933 until 1937. Mr. Morrow has been active in the committee work and other affairs of the Institute, and is at present chairman of the committee on constitution and by-laws and a member of the technical program committee. He is Institute representative on the Engineers' Council for Professional Development, and is a director and past vice-president of the Thomas Alva Edison Foundation.

H. L. Hazen (A'26) has been appointed professor and head of the department of electrical engineering of Massachusetts Institute of Technology, Cambridge. Doctor Hazen was born August 1, 1901 at Philo, Ill., and received the degrees of bachelor of science in electrical engineering (1924), master of science in electrical engineering (1929), and doctor of science in electrical engineering (1932) at MIT. He joined the teaching staff of MIT in 1926 and was advanced to the rank of associate professor in 1936. Aside from his academic work Doctor Hazen has had experience in the laboratories of the General Electric Company and the American Telephone and Telegraph Company. In 1934 he was awarded the Levy Gold Medal of the Franklin Institute for outstanding technical papers on the theory and design of servo-mechanisms. During the same year Doctor Hazen served as an exchange professor at The Ohio State University.

R. E. Hellmund (A'05, F'13, Lamme Medalist '29) has been appointed chairman of the Institute's committee on standards for the year 1938–39. Mr. Hellmund, who is chief engineer of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., was born at Gotha, Germany, in 1879. Attended the Ilmenau Technical College, from which he was graduated with the de-

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K. B. McEACHRON

L. W. W. MORROW

R. E. HELLMUND

R. W. SORENSEN

P. O. CRAWFORD

VANNEVAR BUSH

O. B. BLACKWELL

F. M. FARMER

gree of electrical engineer in 1898. After being engaged in electrical development work for three years, he attended the University of Charlottenburg, Berlin, as a graduate student. In 1903 he came to the United States and held several positions, including a brief affiliation with William Stanley at Great Barrington, Mass., until he was employed by the Western Electric Company, Hawthorne, Ill., in 1905. Since 1907 he has been associated with the Westinghouse Electric and Manufacturing Company, and has been chief engineer of the company since 1933. Mr. Hellmund has been a member of the Institute's standards committee since 1930, and is an alternate member of the electrical standards committee of the American Standards Association.

O. B. Blackwell (A'08, F'17) has been appointed chairman of the Institute's headquarters committee for the years 1938–39. Mr. Blackwell was born at Bourne, Mass., August 21, 1884. Upon receiving the degree of bachelor of science from Massachusetts Institute of Technology in 1906, he immediately entered the engineering department of the American Telephone and Telegraph Company. In 1914 he became transmission and protection engineer, and with the formation of the department of development and research in 1919 he became transmission development engineer. When that department was consolidated with the Bell Telephone Laboratories in 1934 Mr. Blackwell was appointed director of transmission development. In 1935 he was made manager of staff departments and in 1937 became vice-president of the laboratories. From 1936 until 1938 Mr. Blackwell was a vice-president of the Institute representing the AIEE New York City District, and has been a member of several committees. He has participated in the activities of the Edison Electric Institute and the American Standards Association.

F. M. Farmer (A'02, F'13) has been appointed chairman of the Institute's committee on planning and co-ordination for the year 1938–39. Mr. Farmer was born at Ilion, N. Y., in 1877, and was graduated from Cornell University in 1899. In 1903, after spending a year in a test department of the General Electric Company and $2\frac{1}{2}$ years in the inspection division of the United States Navy at the Brooklyn (N. Y.) Navy Yard, he joined the staff of the Electrical Testing Laboratories, Inc., New York, N. Y., then known as the Lamp Testing Bureau. At present he is vice-president and chief engineer of the Electrical Testing Laboratories. Mr. Farmer is a director of the Institute and a member of the technical program committee, the executive committee, and of the committees on standards, finance, and transfers. He is the Institute's representative on the Engineering Foundation board and the Engineering Societies monographs committee, and is a member of the board of trustees of United Engineering Trustees, Inc. Mr. Farmer has been active in various phases of the work of the American Standards Association as chairman or member of several of its sectional committees.

H. M. Sharp (M'34) has been elected general secretary of the Illuminating Engineering Society. Mr. Sharp, who is vice-president of the Buffalo, Niagara, and Eastern Power Corporation, Buffalo, N. Y., was born at Buffalo in 1892, and received the degree of mechanical engineer at Cornell University in 1915. Following his graduation he served briefly as an instructor in mechanical engineering at Cornell University, as an assistant engineer with the Bethlehem Steel Company, Lackawanna, N. Y., and with the United States Army, before becoming efficiency engineer at the Huntley station of the Buffalo General Electric Company in 1919. In 1926 he accepted a similar position with the Indiana Electric Corporation, Terre Haute, Ind., but returned to the Buffalo General Electric Company in 1928 as assistant chief engineer of Huntley station. On completion of the second Huntley station Mr. Sharp was made assistant superintendent of both stations in 1930; in 1931 he became superintendent, which position he held until he was elected to his present position in 1937.

V. P. Hessler (A'29, M'36) has been appointed chairman of the electrical engineering department of the University of Kansas, Lawrence. Doctor Hessler was born September 6, 1903, at Durant, Ia., and received the degree of bachelor of science in electrical engineering from Oregon State College in 1926. In the following year he enrolled in the graduate school at Iowa State College and received there the degrees of master of science in electrical engineering (1927) and doctor of philosophy in electrical engineering (1934). In concurrence with his graduate studies at Iowa State he served as an instructor in electrical engineering. In 1936 Doctor Hessler was promoted to the rank of assistant professor of electrical engineering. He is the author of several papers on carbon brushes for electrical machinery.

F. W. Hurlbert (A'04) has retired from active service in the International General Electric Company, New York, N. Y. Mr. Hurlbert was born June 3, 1870 at Aurora, Ind., and was graduated from Rose Polytechnic Institute in 1891. After serving with various companies he was employed in the railway engineering department of the General Electric Company at Schenectady, N. Y., where he remained five years. In 1901 Mr. Hurlbert was transferred to Buffalo, N. Y., to represent the General Electric Company at the Pan American Exposition in that year. In the following year he entered the foreign department of the company and later was transferred to the New York offices of the International General Electric Company.

G. T. Shoemaker (M'20) recently was appointed general manager of the United Light and Power Company, Kansas City, Mo. A native (1886) of Geneva, Ind., Mr. Shoemaker was graduated from Purdue University in 1910 with the degree of bachelor of science in electrical engineering; in 1916 he received the degree of electrical engineer from that school. Mr. Shoemaker has been associated with the United Light and Power Company and its subsidiaries for more than 25 years, and will serve in a similar capacity with the United Light and Railways Company, Continental Gas and Electric Corporation, and American Light and Traction Company. He will serve the United Light and Power Service Company as president.

Vannevar Bush (A'15, F'24, Lamme Medalist '35) has been appointed chairman of the Institute's Lamme Medal committee for the years 1938–39. Doctor Bush is vice-president of the Massachusetts Institute of Technology and president of the Carnegie Institution of Washington. In announcing his election to the latter position, a biographical sketch of Doctor Bush appeared on page 319 of the July 1938 issue of ELECTRICAL ENGINEERING. For the current year he is the Institute's representative on the council of the American Association for the Advancement of Science and on the National Research Council's division of engineering and industrial research.

F. B. Powers (M'37) has become engineering manager of the combined generator and transportation divisions of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. A native (1904) of Chicago, Ill., Mr. Powers has been associated with the Westinghouse Company continuously since his graduation in electrical engineering from the University of Illinois in 1926. In 1927 he was transferred to the railway motor engineering department, in 1935 was promoted to section engineer of d-c traction motors, and in the following year became manager of engineering of the transportation department.

A. H. Lovell (A'12, M'13, vice-president) has been appointed chairman of the Institute's committee on economic status of the engineer. He is assistant dean and secretary of the University of Michigan, Ann Arbor. A

A. H. LOVELL

biographical sketch of Dean Lovell appeared on page 140 of the March 1938 issue of ELECTRICAL ENGINEERING, in announcement of his nomination as vice-president of the AIEE Great Lakes District.

R. W. Krass (A'06, M'12) recently was appointed central station manager of the eastern district of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., with offices at New York, N. Y. Since 1935 Mr. Krass has been manager of the marine division of the company's eastern district, and will continue to hold that position. He was graduated from Cornell University with the degree of mechanical engineer in 1906, in the same year joining the Westinghouse, Church, Kerr Company as an electrical engineer. In 1910 he became affiliated with the New York Edison Company as cable engineer, and in 1918 left that company as assistant chief engineer.

F. D. Newbury (A'07, F'21) has been appointed manager of the new products division of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Born in Brooklyn, N. Y. and graduated from Cornell University with degree of mechanical engineer in 1901, Mr. Newbury has been associated with the Westinghouse Company continuously in several positions. Besides his regular engineering work Mr. Newbury edited *The Electric Journal* when it was established in 1904. In 1935 he became assistant to the vice-president and later was appointed economist with the company, a position he still retains. He was a director of the Institute from 1918 until 1922.

K. W. Mowry (A'31) now is electrical distribution engineer for the Houston Lighting and Power Company, Houston, Texas. Mr. Mowry has been operating departmental foreman for the U. S. Phosphoric Products Corporation, Tampa, Fla.

L. H. Allcorn, Jr. (A'38) now is maintenance engineer for Briarcliff Lodge, Briarcliff Manor, N. Y. Formerly Mr. Allcorn was engineer for Hazelett Metals, Inc., Greenwich, Conn.

W. A. Laning, Jr. (A'29) has been appointed assistant professor of electrical engineering at the University of Maryland, College Park. Doctor Laning was born at New Kensington, Pa. in 1906 and was graduated from Bucknell University with the degree of bachelor of science in electrical engineering. Later he received the degrees of master of science in electrical engineering and doctor of philosophy from the University of Illinois. Until his recent appointment he was a member of the faculty of Gettysburg College.

F. H. Doremus (A'24, M'32) has become district manager of the industrial department, General Electric Company, Denver, Colo. A native (1901) of Neligh, Nebr., and a graduate of the University of Nebraska in the class of 1922, Mr. Doremus has been associated with the General Electric Company continuously since his graduation, and has been in the Denver offices of that company since 1925.

A. G. Gower, Jr. (M'38) has become associate electrical engineer for the bureau of agricultural engineering, division of plans and service, United States Department of Agriculture, Washington, D. C. Formerly Mr. Gower was employed by the Westinghouse Electric and Manufacturing Company as a central station engineer at Boston, Mass.

F. T. Hague (A'14) has been transferred to the South Philadelphia (Pa.) works of the General Electric Company as manager of engineering of the steam division. Formerly Mr. Hague was manager of the d-c eingneering department at the East Pittsburgh (Pa.) works of the company.

W. P. Graham (A'02, F'23) has been awarded the honorary degree of doctor of laws by Colgate University. He is chancellor of Syracuse University, Syracuse, N. Y., and has been affiliated with that institution for 40 years.

W. O. Ray (A'35) has been advanced from instructor to assistant professor in electrical engineering at the Michigan College of Mining and Technology, Houghton.

Obituary

Dan E. Carpenter (M'15) dean of the faculty of the International Correspondence Schools, Scranton, Pa., died September 7, 1938. Mr. Carpenter was born October 21, 1866, at Starruca, Pa., and was graduated from Pennsylvania State College with a degree in electrical engineering in 1899. Following his graduation he became electrician in charge of equipment at the Pennsylvania State Reformatory, Huntingdon, but after two years was appointed assistant to the engineer of the Sprague Electric Company at Bloomfield, N. J. He first became associated with the International Textbook Company in 1905 as a technical writer. Two years later he was employed in the publication department of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., where he remained until 1913. In that year he returned to the employ of the International Textbook Company as assistant manager of the textbook department, and three years later was appointed dean of the faculty of the International Correspondence Schools. In 1924 Mr. Carpenter assumed the additional responsibilities of vice-president of the International Textbook Company.

Victor Frederiksen (A'32) electrical engineer for the National Electric Coil Company, Columbus, Ohio, died April 23, 1938. Mr. Frederiksen was born January 7, 1895, at Rödkärsbro, Denmark, and attended the Katedralskolen of Viborg (Denmark). In 1912 he came to the United States and received employment with the Norfolk and Western Railway Company, Roanoke, Va. Following brief affiliations with the Virginian Railway Company, the West Virginia Armature Company, and the American Armature Company, he became foreman of the coil manufacturing department of the Charleston Electrical Supply Company in 1921. Five years later Mr. Frederiksen became electrical engineer for the National Armature and Electric Works, Columbus, later holding a similar position with the National Electric Coil Company.

Edwin Ruthven Weeks (A'87, M'87, F'13) retired consulting electrical engineer, Kansas City, Mo., died August 17, 1938. Mr. Weeks was born December 25, 1855, at New York, N. Y., and received his formal education at the Phillips Exeter Academy. He founded the first commercial electric light company in Kansas City in 1881 and became its superintendent and manager in 1882. In 1900 he sold the Kansas City Electric Light Company and formed the consulting-engineering firm of Weeks, Kendall, and Newkirk. Mr. Weeks was an active participant in the early affairs of the former National Electric Light Association, of which he was president during 1889–90. Although Mr. Weeks was most generally known for his pioneering in the electric light and power industry, he was known nationally as a humanitarian.

William J. K. Sutherland (A'15) superintendent of the electric construction division of the Rochester Gas and Electric Corporation, Rochester, N. Y., died in March 1938, according to word just received at Institute headquarters. Mr. Sutherland was born April 6, 1875, in Scotland. In 1894 he was employed by the Rochester Electric Railway and Light Company. He remained with that company until 1921, eventually becoming construction and electrical foreman. Mr. Sutherland became superintendent of electrical construction for the Rochester Gas and Electric Corporation in 1921 and served continuously in that capacity.

Leo Brandenburger (A'37) manufacturers' representative, Salt Lake City, Utah, died February 11, 1938. Mr. Brandenburger was born November 5, 1880 at Linneus, Mo., and was graduated from the University of Missouri with the degree of bachelor of

science in electrical engineering in 1903. Immediately following his graduation he was employed by the Telluride Power Company at Provo, Utah, where he remained until 1912 in various positions. Fom 1912 until 1915 he was superintendent of power sales for the Utah Power and Light Company, Salt Lake City. In the latter year he became sales engineer for the Wagner Electric Corporation; in 1918 he was appointed branch manager, and his service in that position extended over a period of almost 20 years.

William George Nagel (A'03) president of the Zonolite Company, Detroit, Mich., died July 20, 1938. Mr. Nagel was born May 22, 1873 at Wapakoneta, Ohio, and was graduated from The Ohio State University with the degree of mechanical engineer in 1895. Following three years of electrical construction work he became president and manager of the W. G. Nagel Electric Company, Toledo, Ohio. He continued in that business until 1935, when he became president of the Zonolite Company.

Herbert Charnock Jennison (A'05) technical manager of the American Brass Company, Waterbury, Conn., died June 12, 1938. Mr. Jennison's early experience was gained in the laboratories of the Coe Brass Manufacturing Company, Ansonia, Conn., and he had been associated with the American Brass Company since 1913.

Charles Anthony Miller (A'21) secretary of the Okonite Company, Passaic, N. J., died August 23, 1938. Mr. Miller was born September 5, 1884, in New York, N. Y. He was employed by the Okonite Company in 1899 and spent all of his business life with that organization.

Membership

Recommended for Transfer

The board of examiners, at its meeting on September 15, 1938, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Dow, James C., Glendale, Calif.
Way, S. B., president, The Milwaukee Electric Railway and Light Company, Milwaukee, Wis.

2 to Grade of Fellow

To Grade of Member

Best, I. W., chief electrician, El Paso Electric Company, El Paso, Texas.
Corzens, B., research engineer, Los Angeles Bureau of Power and Light Company, Los Angeles, Calif.
Dortort, I. K., assistant engineer, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Ennis, A. G., assistant professor of electrical engineering, George Washington University, Washington, D. C.
Fett, G. H., instructor, University of Illinois, Urbana.
Flint, T. R. C., engineer in charge of power department Toronto Hydroelectric System, Toronto, Ont., Canada.
Georgiev, A. M., engineer in charge of design and development of electrolytic condensers, General Motors Corporation, Dayton, Ohio.
McFarland, R., equipment engineer, Southwestern Bell Telephone Company, St. Louis, Mo.
Metzger, A. F., application engineer, General Electric Company, Boston, Mass.
Montgomery, G. D., division transmission engineer, American Telephone and Telegraph Company, Denver, Colo.
Robertson, L. M., transmission and station engineer, Public Service Company of Colorado, Denver.
Robertson, W. G., assistant valuation engineer, State Corporation Commission of Virginia, Richmond, Va.

12 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before October 31, 1938, or December 31, 1938, if the applicant resides outside of the United States or Canada.

United States and Canada

Anderson, L. T., Lewis Institute, Chicago, Ill.
Ballou, H. P., Rural Electrification Administration, Paxton, Ill.
Blaize, L. J., Dallas Power and Light Company, Dallas, Texas.
Bradley, E., Southwestern Bell Telephone Company, Houston, Texas.
Brink, E. H., Standard Oil Company, Niles, Mich.
Cohen, R. L., Philadelphia Board of Education, Philadelphia, Pa.
Cozzens, R. I., Keystone Pipe Line Company, Philadelphia, Pa.
Davies, M. W. H., The Commonwealth Fund, New York, N. Y.
Everett, R. R., Electrical Engineers Equipment Company, Melrose Park, Ill.
Fraser, E. G., Canada Wire and Cable Company, Ltd., Toronto 2, Ont., Canada.
Gertzon, N., M. W. Kellogg Company, New York, N. Y.
Giobbi, J., Tennessee Valley Authority, Pickwick Dam, Tenn.
Hall, J. E., Jr., Louisiana Power and Light Company, Algiers, La.
Heemer, W. L., Southwestern Bell Telephone Company, Houston, Texas.
Holden, H. Jr., Southwestern Bell Telephone Company, Houston, Texas.
Jennings, J. E., Southwestern Bell Telephone Company, Houston, Texas.
Jolliff, B. N., City Signal Building, Forth Worth, Texas.
Keathley, T. L., Southwestern Bell Telephone Company, Houston, Texas.
McDermott, B., Southwestern Bell Telephone Company, Oklahoma City, Okla.
McNeill, H. E. Imperial Irrigation District, Imperial, Calif.
Melloh, A. W., University of Minnesota, Minneapolis.
Miner, R. W., New York Telephone Company, New York, N. Y.
Moore, H. G., General Electric Company, Erie, Pa.
Nelson, V. J., Washington Water Power Company, Wallace, Idaho.
Ohnell, E., Jr., Kerite Cable Company, New York, N. Y.
Parr, V. P., Southwestern Bell Telephone Company, Houston, Texas.
Redmann, A. J., 5736 Midway Park, Chicago, Ill.
Riley, G. H., Southwestern Bell Telephone Company, St. Louis, Mo.
Ross, R. D., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Schutz, T., Southwestern Bell Telephone Company, Houston, Texas.
Waldron, R. C., (Member) Okonite Company, Passaic, N. J.

Total, United States and Canada—31

Elsewhere

Cervino, C. A., International Business Machines Corporation, Caracas, Venezuela.
Gill, T., (Member) Rangoon Electric Tramway and Supply Company Ltd., Rangoon, Burma.
Inarritu, F., (Member) Comisión Federal de Electricidad, Mexico City, Mexico.
MacDonald, N. B., (Member) McColl Electric Works Pty., Ltd., Victoria, Australia.
Mackerras, A. P., Sydney County Council, Sydney, New South Wales, Australia.
Rao, S. P., electrical department, Bezwada Municipality, Bezwada, South India.
Richards, S. H. (Member) Electricity Commission, Savoy Court, Strand, W. C. 2, London, England.
Roast, C. A. (Member) Nigerian Electric Supply Corporation, Bukuru, Northern Nigeria, British West Africa.
Schaer, E., Companía Minera de Oruro, Oruro, Bolivia.
Trivedi, P. R., Junagadh State Electric Supply Works, Veraval, India.
Turco-Rivas, L., Ministry of Public Works, Caracas, Veuezuela.

Total elsewhere—11

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Barrett, Earl J., Don Pedro Dam, La Grange, Calif.
Cervenka, Frank J., 5736 Midway Park, Chicago, Ill.
De Lay, R. E., 77 Prospect Ave., Long Beach, Calif.
Fetter, Charles H., Electrical Research Products, 250 W. 57th St., New York, N. Y.
Kapell, Sidney M., 3043 Emmons Ave., Brooklyn, N. Y.
Marshall, Myron B., Jr., 606 State St., Schenectady, N. Y.
Platterer, Alvin, 776 N. Cass St., Milwaukee, Wis.
Renking, H. L., 208 N. Broadway, St. Louis, Mo.
Robison, R. L., 941 E. Northlake Ave., Seattle, Wash.
Shimp, Robert P., 414 Hampton Ave., Wilkinsburg, Pa.
Skina, Fred A., 626 Ash St., Moscow, Idaho.
Thrush, George H., Jr., 595 Union Trust Bldg., Pittsburgh, Pa.
Whitney, T. G., Electrical Research Products, Inc., 250 W. 57th St., New York, N. Y.
Wilson, Alexander, 315 New Birks Bldg., Montreal, Que., Can.

14 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Society Library, New York, recently are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

ELECTRICAL ENGINEERING. By C. V. Christie. Fifth edition. New York and London, McGraw-Hill Book Company, 1938. 717 pages, diagrams, charts, tables, 9 by 6 inches, cloth, $3.00. This fifth edition of a standard textbook has incorporated additional details of a practical nature to make the book of more permanent value. New material includes the two-reaction method for analyzing the operation of synchronous machines; an outline of the theory of the three-winding transformer; additional information upon induction motors; and a chapter on symmetrical components. The book aims to present a logical development of the theory of electrical circuits and machinery which will give a background for advanced study in any special field.

ELEKTRISCHE ISOLIERSTOFFE. ("Sammlung Vieweg," Tagesfragen aus den Gebieten der Naturwissenschaften und der Technik, Heft 114). By P. Böning. Braunschweig, Ger., Friedr. Vieweg & Sohn, 1938. 134 pages, illustrated, 9 by 6 inches, paper, 8.80 rm. A discussion of the behavior of electric insulating materials on the basis of ionic adsorption at the inner boundary surface. Part I covers general colloidal and physical fundamentals. Part II describes investigations concerning space charge, distribution of potential, residual phenomena, dielectric losses, and ionic breakdown.

BUSINESS CORRESPONDENCE and OFFICE MANAGEMENT. By E. A. Duddy, L. E. Frailey, and R. V. Cradit. Chicago, American Technical Society, 1938. 234 pages, illustrated, 9 by 6 inches, cloth, $1.75. The business letter, its importance, analysis of problems, letter form, and the various kinds of letters constitute the first section of this book. The second is devoted to the modern scientific technique of office management, including organization principles, filing methods, business machines, and other miscellaneous office equipment.

ELEMENTARY PRACTICAL MECHANICS. By J. M. Jameson and C. W. Banks. Fourth edition. New York, John Wiley and Sons, 1938. 363 pages, illustrated, 9 by 6 inches, cloth, $2.75. Designed primarily for elementary technical and manual training schools, and as an introductory course in engineering colleges.

Pamphlet Copies of Papers Available

¶ Limited quantities of pamphlet copies of the technical papers listed, representing surplus stock remaining from recent AIEE conventions and District meetings, are still available.

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Papers Presented at North Eastern District Meeting, Lenox, Mass., May 18–20, 1938

No.	Authors	Titles of Papers (Some Shortened)
☐ 38-40	McEachron	*Multiple Lightning Strokes—II
☐ 38-41	Lennox & DeBlieux	*A Direct-Current Transformer
☐ 38-42	LaPierre & Mansfield	*Photoelectric Weft-Straightener Control
☐ 38-44	Sporn & Gross	*Protector-Tube Application and Performance on 132-Kv Lines—II
☐ 38-45	Brosnan	*System Planning and Operation for Voltage Control
☐ 38-46	Benner & Lunge	*Voltage-Regulating-Equipment Characteristics
☐ 38-47	Landis	*Voltage Regulation and Control of Rural Lines
☐ 38-48	Burrell & Appleton	*The Periodic Voltage Survey as a Basis for Distribution Design
☐ 38-49	Rogers	*Regenerative Tension Control for Paper Winders
☐ 38-50	Bendz	*Comparison of Methods of Stopping Squirrel-Cage Induction Motors
☐ 38-51	Von Sothen	*The Application of Capacitors in Industrial Plants
☐ 38-52	Vogel	*Corona Voltages of Typical Transformer Insulation

Papers Presented at Summer Convention, Washington, D. C., June 20–24, 1938

☐ 37-58	Smith & Weygandt	*Double Line-to-Neutral Short Circuit of an Alternator
☐ 37-866	Appleman	*The Cause and Elimination of Noise in Small Motors
☐ 38-53	Calvert	Amplitudes of the MMF Harmonics for Fractional Slot Windings
☐ 38-54	Porter	Positive-Grid Characteristics of Triodes
☐ 38-55	Bewley	Traveling Waves Initiated by Switching
☐ 38-56	Subcommittee Report	Line-Type Lightning-Arrester Performance Data
☐ 38-57	Fonda	The Fundamental Principles of Fluorescence
☐ 38-58	Whitehead	*Lightning Protection of 22-Kv Substations
☐ 38-59	Poritsky	Graphical Field-Plotting Methods in Engineering
☐ 38-60	Reagan	*A Self-Checking System of Supervisory Control
☐ 38-61	Race	*Tests on Oil-Impregnated Paper—III—Fluid Flow
☐ 38-62	Spurck & Strang	A New Multibreak Interrupter for Fast-Clearing Breakers
☐ 38-63	Champe & Von Voigtlander	System Analysis for Petersen Coil Application
☐ 38-64	Gulliksen	A Position Regulator for Paper Slitters
☐ 38-65	Prince & Williams	The Current-Limiting Power Fuse
☐ 38-66	Clem	Application of Capacitance Potential Devices
☐ 38-67	Curry	The Co-ordination of Mathematics and Physics
☐ 38-68	Malti	Mathematics and Physics in Engineering
☐ 38-69	Stanley	An Analysis of the Induction Machine
☐ 38-70	Brownlee & Dent	Remote Control of Network Protectors
☐ 38-71	Bellaschi & Aggers	Radio-Influence Characteristics of Electrical Apparatus
☐ 38-72	Cole	Flashover Characteristics of Transformer Condenser Bushings
☐ 38-73	Terman	Analysis and Design of Harmonic Generators
☐ 38-74	Schelkunoff	Transmission Theory of Spherical Waves
☐ 38-75	Lyman & North	*Application of Large Phase-Shifting Transformer
☐ 38-76	Morgan	Co-ordination of Mathematics and Physics With EE Subjects
☐ 38-77	Inglis	*Transmission Features of the New Telephone Sets
☐ 38-78	Wahlquist & Taylor	Noise Co-ordination of Rural Power and Telephone Systems
☐ 38-81	Jones	*Instruments for the New Telephone Sets
☐ 38-82	Teare	A Course to Develop Facility in Mathematics and Physics
☐ 38-83	Bryant	Co-ordination of Physics With Electrical Engineering
☐ 38-84	Sporn & St. Clair	Tests and Performance of a High-Speed Multibreak Breaker
☐ 38-85	Dickinson	"De-ion" Air Circuit Breakers
☐ 38-86	Sandin	Enclosed Low-Voltage "De-ion" Breaker of High Capacity
☐ 38-87	Treanor	The Wound-Core Distribution Transformer
☐ 38-88	Sorensen	The Economic Status of the Engineer
☐ 38-90	Williams	*Combined Thyratron and Tachometer Control of Small Motors
☐ 38-91	Summers	A Static Constant-Current Circuit
☐ 38-92	Hazeltine	Basic Equations for Electric and Sound Radiation
☐ 38-93	Inman & Thayer	Low-Voltage Fluorescent Lamps
☐ 38-94	McDermott	High-Voltage Gaseous and Fluorescent Tubes
☐ 38-95	Pakala	A Memory Attachment for Oscilloscopes
☐ 38-96	Kouwenhoven & Lotz	Absolute Power Factor of Air Capacitors
☐ 38-97	Rusher & Mershon	The Electric Strain Gauge
☐ 38-98	Concordia, Crary & Lyons	Stability Characteristics of Turbine Generators

Papers Presented at Pacific Coast Convention, Portland, Ore., August 9–12, 1938

☐ 38-43	Lightning Arrester Subcom.	Testing and Application of Lightning Arresters
☐ 38-99	Monroe	Electrification of the San Francisco-Oakland Bay Bridge Railway
☐ 38-100	Whelchel	Trends in Electrical Equipment in Hydraulic Power Plants
☐ 38-101	McMillan	Polarity Limits of the Sphere Gap
☐ 38-102	Smith	Use of Bismuth Bridge Magnetic Fluxmeter for A-C Fields
☐ 38-103	Shuck	A Variable-Register-Ratio Watt-Hour Meter
☐ 38-104	Thomson	Similitude of Critical Conditions in Ferroresonant Circuits
☐ 38-105	Morris	Application of Copper-Oxide Rectifiers
☐ 38-106	Wagner	Self-Excitation of Induction Motors
☐ 38-107	Ager	Determination of Induction-Motor Performance
☐ 38-108	Dalziel	Static Power Limits of Synchronous Machines
☐ 38-109	Peterson	General Operation of Transmission Line
☐ 38-110	Cozzens & Peterson	Corona Experience on Transmission Line
☐ 38-111	Cozzens	Insulation and Lightning Protection
☐ 38-112	Laughlin	Carrier-Current Equipment
☐ 38-113	Draper	Transmission-Line Relay Protection
☐ 38-114	Skellett	Narrow-Band Transmission System for Animated Line Images
☐ 38-115	Norwine	Controlling Amplitude Characteristics of Telephone Signals
☐ 38-116	Gaylord	The Pumping System of the Colorado River Aqueduct
☐ 38-117	Skilling	The Electrical Strength of Air at High Pressure
☐ 38-118	Pierce and Hamilton	Phase-Angle Control of System Interconnections
☐ 38-119	Lyon	The Electrostatic Unbalance of Transmission Lines

* These papers have been published in the TRANSACTIONS section of ELECTRICAL ENGINEERING.

Transactions

Papers and Discussions Comprising Pages 559–612 of the 1938 Volume

Instruments for the New Telephone Sets

By W. C. JONES
MEMBER AIEE

Synopsis: Transmitters and receivers for use at subscribers' telephone stations have been designed which not only materially improve transmission but also simplify manufacture and facilitate maintenance. This paper discusses these improvements and describes some of the new design technique employed in their development.

AS A RESULT of continuous development work on transmitters and receivers for use at subscribers' telephone stations, new instruments have been designed which not only materially improve transmission but also embody features which simplify manufacture and facilitate maintenance. These instruments are now being produced for use in handsets, desk stands, and wall sets in the Bell System.[1]

In many respects these instruments represent outstanding advances in transmission instrument design and performance. It is the purpose of this paper to discuss these improvements and to describe some of the new design technique employed in their development. The data presented will be confined almost entirely to physical measurements which serve to define the performance characteristics of the instruments. The interpretation of these data in terms of their relationship to the characteristics of associated apparatus and their over-all reaction on transmission in the telephone plant is covered by a companion paper dealing with the transmission features of the new sets.[2]

Handset Applications

The new transmitter unit with an adapter was first introduced in 1934 as a replacement for the earlier type of handset transmitter.[3] There are now about five million of these transmitters in use in the plant of the Bell System. While experience has shown that they effect an outstanding improvement in performance they do not take full advantage of the possibilities of the unit type of construction from the standpoint of simplification, owing to the fact that a number of additional parts are required to mount the unit on the existing type of handset handle. The advantages of the unit type of instrument have been realized in a new design of handset introduced during 1937, about a million of which have been produced. This handset is shown with the new combined set in the photograph, figure 1, and in cross section on figure 2.

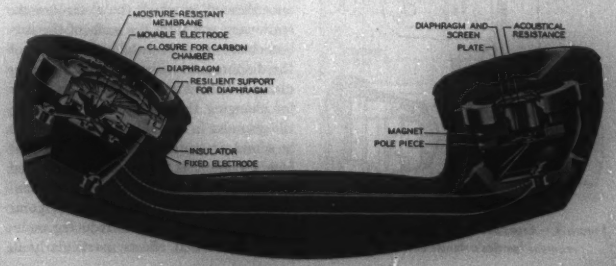
Figure 1. Handset and desk stand equipped with the new instruments

In designing this handset every effort has been made to obtain the maximum degree of simplicity consistent with the electrical requirements involved and at the same time to secure an attractive design which harmonizes with the other station apparatus on the subscriber's premises. Only three phenol plastic parts are employed; namely, the handle and the transmitter and receiver caps. In designing these parts particular attention has been paid to providing adequate cross sections at the points of maximum stress and to distributing the weight so as to reduce to a minimum the breaking moments which are developed when the handset is dropped. The transmitter and receiver caps serve the dual purpose of holding the units in place and providing mechanical protection. In addition they thoroughly insulate the user from all the metal parts which are included in the electrical circuit. Both caps have smooth surfaces which can be readily cleaned. As will be pointed out later, the grid of the receiver cap also has a transmission function and plays an important part in determining the response in the upper frequency range. Spring contacts are provided to facilitate the assembly of the units in the handle. This operation is further facilitated by the fact that specific alignment of the units and the caps relative to the handle is unnecessary. The spacing between the transmitter and receiver is such that the handset can be used with the existing type of desk mounting as well as with the new combined set.

Desk-Stand and Wall-Set Applications

The photograph, figure 1, also shows the new transmitter and receiver unit

Figure 2. Cross section of the handset



Paper number 38-81, recommended by the AIEE committee on communication and presented at the AIEE summer convention, Washington, D. C., June 20–24, 1938. Manuscript submitted April 18, 1938; made available for preprinting May 27, 1938.

W. C. JONES is transmission instruments director of the Bell Telephone Laboratories, Inc., New York, N. Y.

1. For all numbered references, see list at end of paper.

adapted to desk-stand and wall-set use. Cross sections of these instruments are shown on figure 3. The faceplate, mouthpiece, and protective grid of the transmitter are combined in one phenol plastic part which is so designed as to reduce cavity resonance to a minimum and provide response characteristics essentially the same as those of the handset transmitter. On the other hand, the mouthpiece is sufficiently prominent to encourage the user to talk directly into it and in this way reduce the losses which often result when flush-type faceplates are employed with desk-stand and wall-set instruments. A phenol plastic part, equipped with contact springs, holds the unit tightly in the faceplate and provides electrical connections.

As in the handset the unit of the receiver is held in place by the cap. Springs are provided in the shell for bringing out the electrical connections. A metal insert adds sufficient weight to meet the switch hook requirements of the existing sets. The phenol plastic parts of both the receiver and transmitter are so designed as to thoroughly insulate the units and minimize breakage.

Transmitter Unit

The new transmitter unit is of the "direct action" type, that is, one in which the movable electrode serves the dual purpose of contact and pressure surface. As is shown by figure 2, this electrode is mounted at the center of a diaphragm of thin aluminum alloy formed into a shallow cone and ribbed to add rigidity. "Books" of thin impregnated paper mounted in a recess in a die-cast frame provide a resilient support for the edge of the diaphragm. The fixed electrode is held in place in the frame by a threaded ring and is insulated from the frame by a phenol fiber washer and a ceramic insulator which also forms one of the surfaces of the carbon chamber. The active surfaces of both electrodes are gold plated. A silk annulus clamped at its outer edge between the ceramic insulator and the frame and its inner edge between the movable electrode and the diaphragm forms a resilient closure for the carbon chamber. Electrical connection between the movable electrode and the frame is provided by means of metal strips of low stiffness. Provision is made for machine filling the carbon chamber through a hole in the fixed electrode and closing this hole by means of a cap which crimps over a projecting shoulder. The exposed surfaces of the cap and the threaded ring are silver plated and form the contact surfaces for the electrical connections. A moisture-resistant membrane protects the internal parts of the unit from the effects of condensed moisture from the breath. This membrane is clamped at its outer edge between a protective grid of perforated metal and the frame. A thin metal ferrule fastens the grid to the frame. The exposed parts of the unit are anodically finished to resist corrosion.

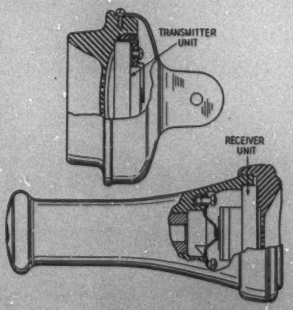


Figure 3. Cross sections of the transmitter and receiver for desk stands and wall sets

In addition to being simpler than the earlier transmitter and hence less difficult to produce, the new transmitter unit has characteristics such that:

1. Its performance is less affected by angular position.
2. There is less aging under the conditions encountered in service.
3. The electrical output is higher and the response more uniform.
4. The modulation products resulting from nonlinearity are materially reduced.

Effect of Angular Position

In order to insure good contact between the carbon granules and the diaphragm in the positions in which the handset is most likely to be held in service, the carbon chamber of the earlier transmitter was placed in front instead of the conventional location in back of the diaphragm.[4] The positional characteristics of this transmitter were further improved by the use of a "barrier" type of variable resistance element in which the electrodes are stationary and form the walls of the carbon chamber, and in which the surface of the diaphragm in contact with the granules is insulated and serves only as means for changing the contact forces between the granules in response to the variations in sound pressure at the diaphragm surface. While this transmitter represented a distinct advance in handset performance from a transmission standpoint and was quite effective in reducing undesirable positional effects, particularly in

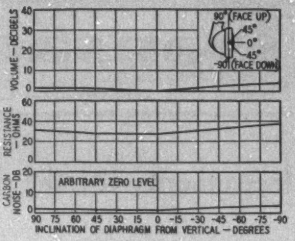


Figure 4. Positional characteristics of the transmitter

the "horizontal face-up" position, it was somewhat complicated mechanically and involved the problem of providing a closure between the diaphragm and the adjacent electrode which would be sufficiently resilient to meet the transmission requirements and at the same time prevent carbon leakage. In addition, there was some degradation in quality when it was held in the "horizontal face-down" position where the carbon granules tended to fall away from the diaphragm. While this condition occurred only infrequently in service, it was one which it was considered desirable to eliminate if this could be accomplished without making the structure mechanically complex or difficult to manufacture or maintain. A tendency also was observed in the field for the resistance to increase sufficiently under certain conditions to react adversely on the operation of the associated signaling apparatus. Owing to the inherently small areas of the sound passages leading to the diaphragm the moisture condensed from the breath could not be excluded by a membrane without complicating the structure and adding sufficient mechanical impedance to impair transmission.

Following the introductory work on the barrier transmitter, an intensive study of the direct-action type of carbon element was made to determine whether the limitations of the earlier structures of this type, which arose from the nonfluid character of the carbon, could be overcome. This study resulted in the transmitter unit shown on figure 2. This unit eliminates the undesirable features of the inverted type without sacrificing its desirable characteristics.

The electrode surfaces of the new transmitter unit are so proportioned and so spaced relative to each other that the important current paths shift their locations in the carbon mass with changes in angular position in a manner such that the mean effective pressures in the paths and the lengths of the paths result in sub-

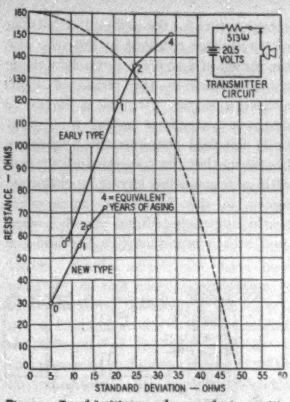


Figure 5. Limiting values of transmitter resistance

stantially constant resistance in all positions. Furthermore, the components of the axial motion of the diaphragm effective in changing the contact forces in the paths are also such as to produce essentially constant modulation. Not only is the total resistance of the paths between the electrodes substantially constant, but this resistance also is uniformly distributed between the individual contacts with the result that at no time does the contact potential rise to a value sufficiently high to produce objectionable carbon noise or "burning." These features result in resistance, volume efficiency and carbon noise characteristics which, as is shown by figure 4, are essentially independent of angular position.

Another and perhaps a more exacting criterion of the adequacy of a transmitter from the standpoint of its ability to function satisfactorily in all positions is the extent to which its transmission characteristics at normal speech intensities are adversely affected when immediately preceded by loud speech. If a poorly designed transmitter is held in a position such that the carbon granules tend to fall away from the movable electrode when this test is applied, the nonfluid action of the carbon will prevent the re-establishment of contact with the electrode surface with the result that volume losses of as much as 20 decibels and a serious degradation in quality take place. Furthermore, these losses persist until the transmitter is jarred or moved about sufficiently to change the configuration of the granules. On the other hand, if the effect of the frictional forces within the granular mass has been taken fully into account in the design of the carbon element, these forces will not react in a manner such as to prevent good contact with the electrode following the large amplitude produced by loud speech and uniform volume and good quality will obtain at all times. The new transmitter meets this test with a substantial margin.

Carbon leakage is prevented in the new instrument without impairment of transmission by the resilient silk closure for the carbon container previously mentioned.

Aging

Transmitter design has advanced to a stage where heating at the points of contact in the carbon element need no longer be an important source of aging. Therefore, such aging of the granular material as occurs in a well-designed instrument is limited almost entirely to that resulting from changes in the properties of the granules caused by abrasion of their surfaces when the transmitter is subjected to mechanical shocks such as occur when the handset is placed on the mounting. As in the case of the earlier transmitter, the new transmitter is machine filled[3] with the result that the motion of the granules and the resultant surface abrasion is reduced to a minimum.

The changes in resistance due to the residual aging have little adverse effect in so far as volume is concerned. In fact, the constants of most of the circuits in which the transmitter is used are such that an increase in resistance adds to rather than decreases the electrical output because of the greater amount of power supplied to the transmitter from the central office battery.

On the other hand, an increase in resistance, though small, may prove to be important in certain circuits where a critical relationship between transmitter resistance and the performance of associated apparatus exists. Under these conditions variations in transmitter resistance may result in failure of the associated apparatus to perform satisfactorily if certain limiting values of resistance are exceeded. In determining the limits to be placed on these values account must be taken of all the variables in the circuit in which the transmitter is connected. Obviously combinations of variables of this nature cannot be dealt with on the basis of averages alone but must include some measure of their range, such, for example, as the standard deviation.[4] The available data indicate that average transmitter resistances and standard deviations which lie within the area bounded by the dotted curve, figure 5, will have no adverse effect on circuit operation in the Bell System plant. This curve is based on certain marginal circuits of which there are a number in everyday use. An important transmitter resistance in determining the performance of associated apparatus in these circuits is the resistance during the period when the call is being established. This resistance is referred to as the signaling resistance. As is shown by the solid curves the signaling resistance of the earlier type of transmitter after artificial aging by an amount considered to be the equivalent of four years in service falls outside the acceptable area. On the other hand the resistance of the new type when aged and measured under identical conditions falls well within the limiting curve and hence not only requires less frequent replacement but also permits greater freedom in circuit design and plant layout.

Moisture condensed from the breath is an important factor in determining the life of a transmitter. A protective membrane is provided in the new transmitter unit which not only is highly moisture resistant but also results in no appreciable transmission impairment. The characteristics of the material employed in this membrane are such that it is not affected by the aging conditions encountered in service such, for example, as the alkaline reaction of water after it has been in contact with phenol plastic parts or tobacco ashes. The exposed metal parts are finished to resist the corrosive action of these agents.

Response

Reducing the transmitter to an equivalent electrical circuit provides a useful means for analyzing its performance and determining the extent to which the individual parts contribute to its response.

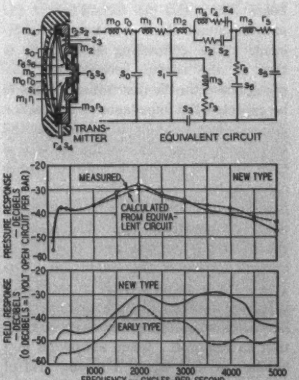

TRANS-MITTER
EQUIVALENT CIRCUIT
MEASURED
CALCULATED FROM EQUIVALENT CIRCUIT
NEW TYPE
EARLY TYPE
PRESSURE RESPONSE (DECIBELS BELOW 1 VOLT OPEN CIRCUIT PER BAR)
FIELD RESPONSE (DECIBELS BELOW 1 VOLT OPEN CIRCUIT PER BAR)
FREQUENCY — CYCLES PER SECOND

Figure 6. Pressure and field-response characteristics of the transmitter

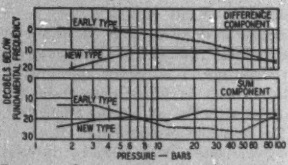


Figure 7. Sum and difference components as a function of the intensity of the fundamental frequencies

Such a circuit for the new unit is shown on figure 6.

While the diaphragm can be represented as a lumped mass for frequencies in the region below 3,500 cycles per second, it is necessary to consider it as being composed of three masses coupled by stiffnesses in order to adequately represent its performance at higher frequencies. These masses consist of the central portion m_5, the ribbed intermediate portion m_2 and the outer portion m_4. The central portion includes the mass of the movable electrode and is coupled to the ribbed portion by the stiffness s_6 which in turn is coupled to the outer portion by the stiffness s_3. The paper books which support the edge of the diaphragm have a stiffness s_4 and a resistance r_4. Their mass is included in the mass of the outer portion of the diaphragm m_4. The internal resistances of the portions which form the coupling stiffnesses s_3 and s_6 are represented by r_3 and, r_6 respectively. A hole is provided in the diaphragm to permit rapid equalization of low-frequency pressures of high intensity and prevent damage to the diaphragm and other parts. The mass and resistance of this hole m_0r_0 are so chosen that their effect on response is confined to frequencies below 300 cycles per second where the station circuit itself is relatively inefficient. The controlling stiffness s_2 is that of the cavity between the diaphragm and the die-cast frame. As is to be expected the impedance of the carbon granules is a function of amplitude and frequency. However, for the purpose of this type of analysis, their impedance characteristics can be represented to a first approximation by a constant stiffness and resistance r_5s_5. The mass of the carbon is lumped with that of the central portion of the diaphragm. The grid of the transmitter unit proper is provided for mechanical protection only and has holes large enough to have no reaction on response. When assembled in a handset or desk stand a second grid of insulating material is added. The holes of this grid have a mass and resistance, m_0r_0, which must be taken into account in arriving at an over-all picture of the factors affecting response. These holes are coupled to the moisture-resistant membrane m_1r_1, by means of the stiffness s_0 of the enclosed cavity. The cavity stiffness s_1 couples the membrance to the diaphragm.

There are two types of response-frequency measurements in general use; namely, pressure-response measurements in which a constant sound pressure is maintained at the face of the transmitter throughout the frequency range covered by the test, and field-response measurements in which a sound field of constant intensity is established at each frequency before inserting the test transmitter. Pressure response is used principally for purposes of analysis whereas field response usually affords a better measure of the performance of the transmitter under the conditions of actual use.

The pressure response of the new transmitter measured with a constant sound pressure at the grid, and the response computed from the equivalent circuit are shown on figure 6. The transmitter used in this test was artificially aged by an amount equivalent to two years of service in order to simulate more nearly plant conditions. While the computed curve departs slightly from the measured curve at certain frequencies, due to the inadequacy of some of the basic assumptions, such as those which were made relative to the impedance of the granular carbon, the agreement in general is so good as to provide a powerful tool for predetermining the response characteristics of transmitters under development and a useful method for evaluating the reaction of one element of the transmitter on another. Reducing the transmitter to an equivalent electrical circuit also has proved invaluable in determining the causes of variations in transmitter performance observed during manufacture.

As previously mentioned, the response characteristics of a transmitter under conditions of actual use may differ from those obtained with a constant pressure at its face. In general this is due to the fact that the diffraction effect of the transmitter as an obstacle in the sound field has not been taken into account. While not as readily predetermined as the pressure response, the field response can be easily measured by inserting the transmitter in a sound field of constant intensity. An artificial voice[5] is used in this measurement as a sound source and the electrical input is adjusted to maintain a constant sound pressure at the guard ring at each frequency before inserting the instrument under test. Response curves for the new and early types of transmitter obtained in this way also are shown in figure 6. Both show rising characteristics in the region of 2,000 cycles per second. While it is feasible to design a transmitter having a substantially flat field characteristic, experience has shown that the transmission obtained with a transmitter having a rising response in this frequency region more nearly approaches direct speech,[2] when used with a representative line and the

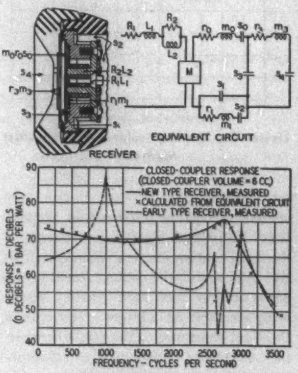

EQUIVALENT CIRCUIT
RECEIVER
CLOSED-COUPLER RESPONSE
(CLOSED-COUPLER VOLUME = 6 CC)
NEW TYPE RECEIVER, MEASURED
×CALCULATED FROM EQUIVALENT CIRCUIT
EARLY TYPE RECEIVER, MEASURED
RESPONSE — DECIBELS (0 DECIBELS = 1 BAR PER WATT)
FREQUENCY - CYCLES PER SECOND

Figure 8. Closed-coupler response characteristics of the receiver

new receiver, than that obtained with one having a more uniform field response.

Nonlinear Distortion

A substantial reduction in nonlinearity has been effected in the new transmitter unit.

It is a well-known fact that the slope of the input-output curve of most transmitters is not unity even for sound intensities other than those at which overloading occurs. However, this departure from nonlinearity does not entirely account for the modulation products developed when two frequencies are impressed on the transmitter. Measurements of the sum and difference components in the output of the new transmitter and the earlier transmitter for frequencies of 1,500 and 1,700 cycles per second are shown on figure 7. It will be noted that whereas the difference component produced by the earlier instrument is equal to the fundamental within the speech range, the sum and difference components are both ten decibels or more below the fundamental at all the intensities measured in the case of the new unit.

A tendency for the difference component to be considerably more pro-

nounced than the sum component in the case of the earlier transmitter is characteristic of all of the commercial instruments measured during the development of the new unit. As previously mentioned, this cannot be fully explained by a nonlinear relationship between input and output. The available data indicate that it is due to the manner in which the resistance changes cyclically when pressure waves of two frequencies are impressed simultaneously on the transmitter. Similar effects also have been observed in the microphonic action of carbon contacts themselves. Hence it is not unlikely that this is a fundamental characteristic of the carbon itself. If this proves to be true the extent to which an improvement can be effected in the performance of the transmitter will depend upon the ultimate control which can be exerted over the basic properties of the granular material.

Receiver Unit

The new receiver unit is of the bipolar permanent-magnet type. The magnetic circuit consists of pole pieces of 45 per cent Permalloy, two straight bar magnets of Remalloy and a Permendur diaphragm.[6] The magnets are welded to the pole-pieces to form a unit which is mounted on projecting lugs on the die-cast frame. The coils are wound with enamel insulated wire interleaved with cellulose acetate. The pole tips project through a phenol fiber plate which is fastened at the edge to the frame to form a cavity in back of the diaphragm. This cavity is connected to the recess in the handset handle or receiver shell by a hole in the plate. A disk of specially prepared silk covers this hole and provides the required amount of acoustical resistance. The silk fabric is so woven that it does not change in resistance with wetting and drying. The front of the unit is protected by a perforated metal grid which is assembled to the frame by means of a thin ferrule. A disk of impregnated silk is mounted between the grid and the frame to form a screen which prevents the transfer of foreign material from the front to the back of the diaphragm when the receiver is dropped. The grid and ferrule are anodically finished to resist corrosion. The spring contact surfaces are silver plated.

Prior to the introduction of this unit the receivers in general use for telephone purposes in this country and abroad employed simple resonant diaphragms and as a result had response characteristics which were characterized by prominent resonance peaks. As a rule the peak due to the first overtone, as well as that due to the fundamental resonance, fell within the important frequency range. This resonance not only introduced frequency distortion but increased the intensity with which circuit disturbances such as clicks were reproduced. Furthermore, the diaphragms of these receivers were rigidly clamped between surfaces which differed in temperature coefficients of expansion and heat capacities from those of the diaphragm with the result that the performance of the receiver was erratic and at a given time was dependent upon the temperature changes to which it had been subjected.

The new receiver is so designed that:

1. All prominent resonances within the important frequency range have been eliminated and the response within this range materially improved.

2. The effect of changes in temperature has been eliminated.

3. These improvements have been accomplished without sacrificing simplicity of design or introducing features which complicate manufacture of the receiver or increase the maintenance required.

Response

An equivalent electrical circuit for the receiver and a typical closed coupler response curve are shown on figure 8. Referring to this figure it will be noted that there are two meshes in the circuit which contain mass, stiffness and resistance and which control the motion of the diaphragm. One of these meshes consists of the acoustical resistance m_1r_1 coupled to the diaphragm $m_0s_0r_0$ by the stiffness s_1 of the cavity between the diaphragm and the plate which surrounds the pole tips. Included in this mesh is the stiffness s_2 of the cavity in the handset handle or receiver shell. The other mesh is composed of a cap grid m_3r_3 and the load s_4 coupled to the diaphragm by means of the cavity stiffness s_3. The grid of the receiver unit proper is provided for mechanical protection only and has holes large enough to have no reaction on response. The mass of the resilient screen is small and is lumped with the diaphragm mass m_0. The electrical portion of the circuit consisting of the winding R_1L_1 and the equivalent eddy current circuit R_2L_2 is coupled to the mechanical and acoustical portion by means of the force factor M.[7]

The response computed from the equivalent circuit for a number of frequencies is included on figure 8. The agreement between this curve and the measured curve is excellent and makes it possible to predetermine the response of the receiver with a high degree of accuracy, and to evaluate the effect on the over-all response of the receiver of changes in the constants of the component parts. This type of analysis also has been invaluable as an aid in establishing the causes of variations in response which have been observed during the development and production of the receiver. A measured response curve of a receiver of the earlier type has been added to figure 8 for convenience of reference. The improvement in uniformity and range of response is obvious. It will be noted that large gains have been effected for frequencies in the range from 1,500 to 3,000 cycles per second.

The response of the receiver to a square-topped wave affords an excellent measure of frequency distortion. Oscillographic records of the output of typical receivers of the new and earlier types are shown on figure 9 for a frequency of approximately 50 cycles per second. The distorting effect of diaphragm resonance is so obvious as to require no comment beyond pointing out that for accurate reproduction of square waves uniform response for an infinite frequency range is required and that the slight rounding of the corners of the wave as reproduced by the new receiver is due primarily to the falling off of its response above 3,000 cycles per second.

The substantially uniform response of the new receiver also renders clicks and other surges much less objectionable. This is due to the fact that the ear does not respond to the peak value of an oscillatory transient alone but integrates the oscillation over an interval at the beginning of the surge, hence the higher the damping the less objectionable the click.

The nonlinear distortion produced by a receiver of the new type is negligible in its reaction on transmission, the harmonics

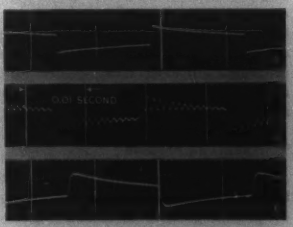


Figure 9. Response of the receiver to square waves

A—Measuring circuit—no receiver
B—Early type receiver
C—New type receiver

in the output being 35 decibels or more below the fundamental.

Magnetic Circuit

Inasmuch as the magnetic properties of the diaphragm, as well as its mechanical properties, must be considered in arriving at the preferred dimensions, it was necessary in designing the new receiver to develop criteria which could be applied in determining the optimum relationships between these factors. This study led to the use of the ratio of the force factor to the effective mass of the diaphragm for this purpose. For given magnetic materials in the pole pieces and the diaphragm and a given air-gap length, there is a pole-face area and diaphragm thickness for which this ratio is a maximum. Typical data illustrating this relationship are shown on figure 10. The available magnetic materials were studied using this technique and a decision was reached to use Permendur in the diaphragm and 45 per cent Permalloy in the pole pieces.

There is a value of polarizing flux for which the force factor of the given magnetic circuit is a maximum. The rate at which the force factor falls off above and below this optimum value of flux is a function of the magnetic characteristics of the materials employed, the length of the air gaps, etc. Without exception the more efficient magnetic circuits have been found to be the most critical as regards polarizing flux. Hence, if wide variations in the efficiency of the product receivers are to be avoided and serious losses due to subsequent demagnetization in service prevented, means must be provided not only for bringing the flux in each receiver to the optimum value, but also for insuring that it remain at this value during the life of the instrument. In order to accomplish this result the magnets of the new receiver are so designed as to overpolarize the magnetic circuit when they are fully magnetized. Equipment is provided for demagnetizing each receiver to its optimum flux value during the assembly process. Receivers which are not sufficiently overpolarized before demagnetization to resist further demagnetization under service conditions are rejected.

Temperature Effects

The diaphragm of the new receiver is held in place by the force developed by the polarizing flux and hence it is free to expand and contract independently of its seating surface. This feature renders the performance of the receiver independent of the changes in temperature to which it has been subjected. The force due to the polarizing flux is sufficiently high to prevent rattling at input intensities many times those of loud speech.

Coupling

Although station circuits can be designed which under ideal conditions result in no sidetone, this objective is never fully realized under actual plant conditions, with the result that a part of the electrical output from the transmitter always reaches the local receiver. Whether the electrical coupling between the transmitter and receiver as evidenced by the residual sidetone is of importance from the standpoint of sustained oscillation or "howling," depends upon the degree of mechanical and acoustical coupling between the instruments. Handset and instrument design has advanced to a stage where mechanical coupling need no longer be a problem. On the other hand, as the response of the instruments is improved, the acoustical coupling may become an important item in determining the howling margin. This margin is so large under the conditions where the new handset is being used for transmission purposes that there is no tendency for oscillation or distortion to occur. However, if the handset is placed face downward on a desk or table, an air column is created which resonates in the region of 2,500 cycles per second. Inasmuch as this is the region where a substantial improvement in the response of the receiver has been effected, a marked reduction in howling margin results. While there is still sufficient margin to meet all of the requirements of field use, this situation serves to emphasize the fact that such factors as acoustic coupling may limit the transmission improvements which can be effected under a given set of operating conditions.

Effective Transmission

The extent to which the better performance of the new instruments is effective in improving the grade of transmission afforded the telephone user is a complex matter and one which is influenced by such factors as the characteristics of the circuits with which the instruments are associated at a given time, the amount of noise present at the transmitting and receiving stations, the reaction of sidetone on the loudness with which the user speaks, the distance between his lips and the face of the transmitter, the tightness with which he holds the receiver to his ear, etc. Many of these factors are beyond the control of

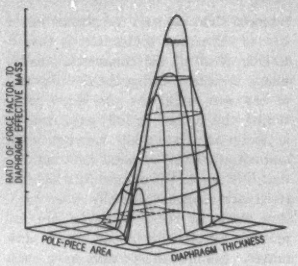


Figure 10. Force-to-mass ratio as a function of diaphragm thickness and pole-piece area

the engineer responsible for the design of the transmitter and receiver and hence can be evaluated, in so far as their reaction on transmission is concerned, only by tests made under the conditions of actual use.

A method has been devised which makes it possible to rate the over-all effect of these factors on transmission in a way representative of the results obtained by the subscribers in their normal use of the instruments.[8] Numerous tests employing this method of rating were made during the development of the new transmitter and receiver to make certain that the course followed in their development would insure the best possible performance under service conditions. Similar tests were also made of the designs selected for production. These tests show that in many respects the new instruments represent outstanding advances in transmission instrument design and performance.

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Combined Thyratron and Tachometer Speed Control of Small Motors

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MUCH has been done in applying thyratrons to motors.[1-4] This paper is restricted to cases where the speed of the motor is measured by an electric tachometer whose output is used to control the motor input. Since this control is made fast by the use of thyratrons, it is possible to hold the speed of the motor constant under difficult conditions or to vary it rapidly in exact accordance with requirements. Three applications of control of this general type are described together with the methods used. The first application is to a null-type high-speed recorder, the second to a high-speed controller, and the third to a motor generator set held in synchronism with a source of frequency normally constant and at low power level.

High-Speed Recorder

One of the principal problems in designing a high-speed recorder is to move the pen or stylus to its final position within the allowed time without overshooting. If the quantity being measured, after making an abrupt change, holds constant at its new value until the chart paper has advanced sufficiently for the pen to draw a short section of straight line, then, any overshooting of the pen if present can be recognized as such and the record can be interpreted without serious error. However, the measured quantity may not be constant at its new value, in which case overshooting is very objectionable because it is impossible to distinguish between overshooting and the true maximum or minimum value of the measured quantity.

In the case of a null-type instrument, such as a slide-wire recorder, inertia is generally large, which fact tends to accentuate overshooting. Inertia is generally large because of certain accessories, and allowance for such accessories, as control disks, slide-wire transmitters, Selsyn transmitters, etc. By avoiding these accessories and redesigning with lighter parts the overshooting can be reduced,[5] but a very good way to eliminate overshooting entirely and at the same time have rugged parts and retain the accessories is to reduce the speed as the balance point is approached.

One way of reducing speed is to reduce motor input, but in general motor input is a poor index of motor speed because of the effect of inertia load, variable friction load, and the limitations of motor characteristics.[6,7] Ways of reducing the speed more definitely have been investigated and it has been found to be most satisfactory to use an electric tachometer to measure speed and control it.

With the use of the tachometer, the motor requirements are simplified. It need only be capable of meeting the maximum torque demand and should, of course, have minimum inertia if maximum speed of recording is desired. A series commutator motor serves very well. The field turns are reduced somewhat below standard d-c practice. This reduces field inductance and gives better performance on the pulsating output of the thyratrons.

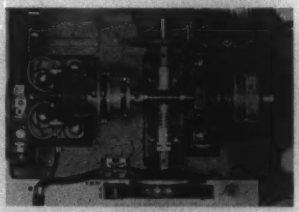

Figure 1. Motor and coupled tachometer

The d-c tachometer for controlling the motor speed is flexibly coupled to an extension of the motor shaft

Figure 2. Combined motor tachometer unit

The d-c tachometer for controlling the motor speed is built into a common frame with the motor

The tachometer is nothing more than a d-c generator with a permanent-magnet field. Figure 1 shows it as a separate unit coupled to the motor through a coupling designed to have maximum torsional stiffness. Figure 2 shows it built integral with the motor.

The motor receives its power through one or the other of a pair of thyratrons, for forward or reverse torque, as required. The connections are indicated schematically in figure 3. This figure shows the recorder as a d-c potentiometer of low range ($2^1/_2$ millivolts).[8] The current through the slide-wire potentiometer is set at a fixed value so that each and every position of the slide-wire contact corresponds to a known voltage and, since the pen moves with the contact as it is driven to the balance point by the motor, the pen position indicates the value of the measured electromotive force.

Any unbalance is detected by a vacuum-tube amplifier. This is not a d-c amplifier as might be supposed. In general d-c amplifiers are subject to a drift in zero. Instead an a-c amplifier is used which can have slight drifts in sensitivity but no drift in zero.

The a-c signal for the amplifier is derived from the unbalanced d-c voltage by the action of a carbon-microphone modulator driven at approximately constant amplitude at line frequency. This form of detector is fast and free from the effects of vibration.

In operation, if there is a sudden decrease in the electromotive force being measured, there will be an unbalanced d-c voltage in this circuit. A current will flow, the microphone will modulate the current, that is, it will produce an a-c component. The a-c component in passing through the primary winding of the low-level transformer will develop an a-c voltage across it. The secondary winding will apply a stepped-up a-c voltage to the amplifier. The amplifier output is connected to a push-pull transformer which in turn is connected to the grids of the thyratrons. The thyratron plates are supplied with an a-c voltage having a definite phase relation to the microphone drive. In one or the other of these thyratrons, the grid will be positive when the plate is positive and this tube will pass current, thus urging the motor to drive the pen downscale.

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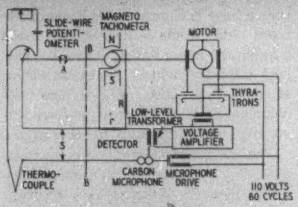

Figure 3. Simplified diagram of potentiometer recorder

As shown, the circuit is arranged for recording the voltage of a thermocouple. When used as a controller the part to the right of *B-B* is unchanged except for the addition of an inductance in series with *R*

If, instead of a sudden decrease, there is a sudden increase of the measured electromotive force the unbalanced direct current will be in the opposite direction, the phase of the alternating current applied to the amplifier will be reversed, so that the grid of the other thyratron will be positive when its plate is positive. It will pass current and urge the motor to drive the pen upscale.

If there is no unbalance there will be no direct current through the microphone, there will be no a-c component, and no motor current.

From this it can be seen that, if the recorder is balanced, it will stay balanced, and if it is unbalanced, it will be urged toward the balanced position (with full torque).

If the recorder consisted of nothing more than this, it would overshoot (and possibly oscillate) due to inertia of the parts, hence the use of the tachometer.

The tachometer voltage is attenuated by a pair of resistors connected as shown. This voltage is then introduced into the circuit of the measured electromotive force so that in operation, the speed of the motor is controlled to maintain the sum of all three voltages in this circuit at zero. In other words, the tachometer voltage is controlled to be equal to the difference between the measured electromotive force and the slide-wire electromotive force. Hence the speed of rebalance tends to be proportional to the remaining unbalance. In this way, the speed is reduced as the balance point is approached so that there can be no overshooting no matter how abrupt nor how large may be the change in the measured quantity.

It is of interest to consider a system of this general type in the case where the only limitations are a fixed torque and a fixed inertia. In this case, the quickest conceivable way to get the system balanced is to throw on full accelerating torque and leave it on up to a certain critical time, at which time the torque should be reversed. If the time be correctly chosen for reversal the system will just come to rest at the balance point. This time can be picked by using a tachometer with a voltage output proportional to the square of the speed. The method is effective for any magnitude of unbalance and for any position of the balance point. This is evident when one considers that the kinetic energy in the motor (and parts that move with it) increases in proportion to the square of the speed and that this energy must never be allowed to exceed that which can be absorbed subsequently by the braking of the motor. The energy which can be absorbed decreases directly with the remaining distance to the balance point.

At every instant the voltage from the square-law tachometer indicates the kinetic energy and the remaining unbalanced voltage indicates the energy which can be absorbed by braking, so, as soon as the former voltage equals the latter, the accelerating torque is turned off and the braking torque is turned on.

In practice, it has been found that the nonlinear current-voltage curve of a copper–copper oxide rectifier[8] when used with a linear tachometer gives a very satisfactory square-law tachometer as indicated by the resulting performance shown in figure 5. It may be noticed that the point of maximum speed does not occur exactly half way toward balance either in distance or in time as it would in the limiting case. The greater time given to deceleration is the result of a margin of safety in the adjustment of the tachometer voltage in order that overshooting may not occur under the worst combination of adverse conditions.

High-Speed Controller

Those familiar with problems of automatic control will recognize in the recorder system just described some features and elements well suited to automatic control. Refer to figure 3 and consider the system to the right of *B-B* as a controller. Disregard the part of figure 3 to the left of *B-B* and consider instead that there is here substituted the machine or system to be controlled. S is an electromotive force which indicates the deviation from normal of the controlled variable such as speed or temperature. A is the position of the control motor shaft and also the position of the rheostat or valve or whatever is involved, but which, in any case, if changed, will sooner or later affect the deviation voltage S.

From the description of the recorder already given (and with a linear tachometer) it is evident that the shaft will be moved at a speed proportional to the deviation voltage S. That is:

$$\frac{dA}{dt} = K_1 S \qquad (1)$$

where t is time and K_1 is a constant. This well-known type of control,[9] which is quite satisfactory for the recorder, is likely to be quite unsatisfactory for controlling a machine or system which in itself has delay or time lag. Quite often if set up to operate with speed sufficient to be useful, it will hunt or cycle.

If the effect of the tachometer is reduced to a negligible amount by increasing R or decreasing r (figure 3) and if at the same time a slide-wire potentiometer with its output connected in series with the deviation voltage S is placed upon the control motor shaft, then the position of the shaft will be controlled to be proportional to the deviation S. That is:

$$A = K_2 S \qquad (2)$$

This well-known type of control[9] is not likely to hunt. It does not, however, reduce to zero the deviation from normal

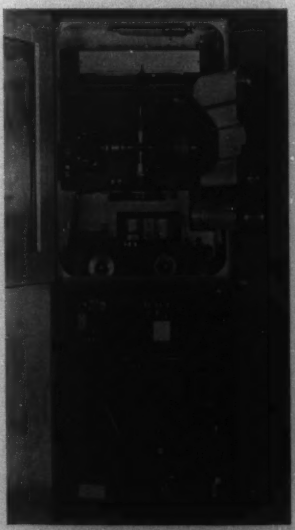

Figure 4. High-speed potentiometer recorder

The upper case contains the motor, tachometer, slide-wire, slide-wire rheostat, pen, and chart while the lower case contains the microphone, low-level transformer, voltage amplifier, and thyratrons

unless equilibrium just happens to be reached for the normal position of the control motor shaft, A.

By omitting the slide-wire and placing in series with the tachometer, inductance as well as resistance we get the well-known type of control[9,10]

$$\frac{dA}{dt} = K_1 S + K_2 \frac{dS}{dt} \qquad (3)$$

or

$$\frac{dA}{dt} = K_4 \left(RS + L \frac{dS}{dt} \right)$$

where R is the resistance in ohms and L is the inductance in henries in the tachometer circuit. L is not shown in figure 3. K_4 is revolutions per second per volt in the tachometer divided by r (the coupling resistor) in ohms. S is the deviation in volts and A the position of the shaft in revolutions. t is time in seconds.

By choosing proper constants this control becomes as stable and fast as type (2) and reduces the deviation to zero as does type (1).

It is of interest that the complete control system uses no elements which are not used in the recorder with the exception of the inductance L. The motor tachometer unit figure 2 is mounted on the rheostat or valve of the system being controlled. This type of controller is of value for processes which require sensitivity and speed in their control, but which in themselves have too great a time lag to permit the use of a simple type of control. The magnitude of the process time lag that can be handled satisfactorily with this type of control is limited by the circuit elements available for use in the tachometer circuit in the controller. Principally, the limitation is in the time constant of these circuit elements.

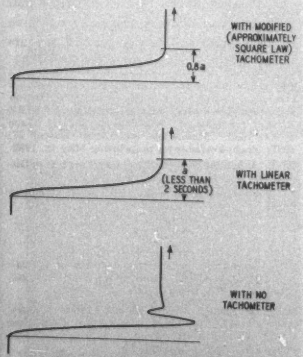

Figure 5. Recorder rebalancing curves

These curves show how overshooting can be eliminated and how the rebalancing time can be reduced by the proper use of a tachometer in a recorder

Synchronized Source of A-C Power

The problem here is to provide an a-c source of several hundred watts synchronized with a signal capable of supplying only a small fraction of a watt. The signal frequency is normally held constant at 60 cycles per second. One possibility is the use of a thyratron inverter, but in some applications a controlled motor-generator seems better suited, because tube capacity requirements are less, the output voltage can be made independent of input voltage variations, and tube failure causes only a loss of frequency control rather than a complete loss of voltage.

The generator is necessarily an a-c machine. The motor is a d-c machine, shunt (or compound) wound, and requires a d-c source of supply. The control of the speed of the shaft is the means whereby the frequency of the generator output is controlled. The speed is controlled by the action of a thyratron on the motor field. For the purpose of control the speed function is obtained by comparing the frequency of the generated a-c wave with the voltage wave of the standard signal. Hence in this application the a-c generator itself serves as the equivalent of a tachometer.

The thyratron is supplied with alternating voltage on its plate from the a-c generator (self-excited) and with alternating voltage on its grid from the controlling signal. In operation, if the machine slows down the plate voltage increases its lag with respect to the grid voltage, more current is passed which weakens the motor field until the speed is returned to normal.

If the cause of the slowing down remains, the field must continue in its somewhat weakened condition as a result of more thyratron current which in turn is maintained by a greater phase lag of the output voltage of the a-c generator with respect to the signal voltage. The control therefore sets motor field proportional to the relative angular *position* of the generator rotor.

When this system was still in the experimental stage and consisted of no more than that described above, it was found that full load variations could be taken care of readily, but that the d-c input voltage had to be maintained within rather close limits. This was not surprising because of the inherent characteristics of a shunt motor with field saturation of the usual amount. Changes in load require only small changes in field (even less if there is compounding), but changes in d-c input voltage require very considerable changes in field. A wide range of d-c input voltage, therefore, dictates that the maximum effect of the thyratron on the field be large. Since this large effect must reduce to zero as the advance in the rotor increases to only one-half of a cycle (180 electrical degrees), the phase control can be said to be "stiff."

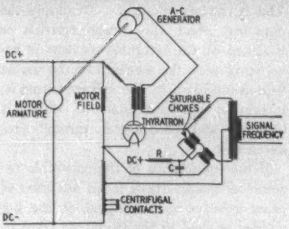

Figure 6. Simplified diagram of synchronized motor generator

This diagram shows, in addition to the basic control, how the voltage across the motor field is integrated by the RC circuit and how the result is used to modify the control

Stiffening the phase control increases the tendency to hunt; hence there is needed some means for counteracting this tendency so that the phase control can be made stiff enough to permit a satisfactory range of d-c input voltage.

The immediate effect of reducing the field on a shunt motor is to reduce the counter electromotive force, increase the armature current, and hence increase the torque. The simple control, as described so far, therefore makes the torque (angular *acceleration* of the rotor) proportional to the relative angular *position* of the rotor. Because it takes no account of the relative angular *velocity* of the rotor the oscillations are not definitely damped, hence the difficulty with hunting. It is not simple to take account of this relative *velocity* by measuring it directly, so instead it was decided to *integrate* the acceleration and to use the result to modify the control as will be explained. Since the *integral of acceleration* is *velocity*, this arrangement gives the desired damping effect and so allows a wide range of d-c input voltage.

A simplified circuit is given in figure 6. Normally the thyratron component of the field is determined by the phase relation between the alternator electromotive force and the signal electromotive force.

This is the basic control. To supply the damping effect this phase relation is modified by the saturable reactors in accordance with the strength of the motor field as indicated by the voltage across it, integrated by capacitance C which is charged and discharged through resistance R.

If the inductance of the saturable reactors decreases there is an advance of phase relative to the signal of the a-c voltage applied to the thyratron (grid to cathode). The saturable reactors are each standard permalloy core transformers and two are used with one winding reversed in order to eliminate transformer action.[11] Each core is saturated equally by a direct current determined by the d-c resistance of the reactors and the voltage across capacitor C. Theory and practice indicate that this current does not interfere with the functioning of C provided C is sufficiently large (50 microfarads).

In operation, when there is a shift in load or d-c input voltage, there is in general an angular shift of the rotor (relative to the signal). The rotor, as observed by a stroboscope, generally overshoots the final angle a few degrees, but after a few damped swings settles definitely into position. No cycles are lost so synchronism is maintained.

If at any time the d-c input voltage is momentarily interrupted or if the machine is overloaded, then synchronism will be lost. However, if conditions within the normal working range are restored before the motor starter drops out, the machine will resynchronize. This is accomplished by the assistance of the centrifugal contacts as shown in figure 6. These contacts play no part as long as the machine is running within a per cent or so of normal speed, one being closed and one being open at this speed. Their action in synchronizing is to cut in and out field resistance thus bringing the machine to within a per cent or so of synchronous speed from either the high or low side. From either of these speeds the machine can readily pull itself into synchronism.

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Lightning Protection of 22-Kv Substations

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ASSOCIATE AIEE

Synopsis: This paper outlines laboratory and field tests with a surge generator and cathode-ray oscillograph which led to the co-ordination of insulation and lightning-arrester performance in substations on the 22-kv subtransmission system of the Duquesne Light Company.

A basic level of 150 kv for station insulation was selected in 1932, and methods of obtaining this level are presented together with the operating record for five years. The index representing the station equipment faults in per cent of total system faults during thunderstorms has decreased 86 per cent following system-wide improvement programs modernizing insulation and arresters.

RECENT papers on basic impulse insulation levels,[1] lightning arrester application,[2] and the general co-ordination problem[3,4] summarize a vast amount of work which has been done to place station lightning protection on a sound theoretical basis for the use of system designers and protection engineers.

Since 1932 the Duquesne Light Company has been actively engaged in an insulation co-ordination and lightning-arrester modernization program guided by this theory and based upon data obtained through laboratory and field tests with a 750-kv surge generator and cathode-ray oscillograph.

Because of the problems encountered in the protection of 22-kv station equipment, and the choice, in 1932, of 150 kv as a basic impulse insulation level, it is felt that a description of practice and results obtained would be timely.

The Problem

In the years 1930 and 1931 severe lightning seasons caused the number of substation equipment failures to reach such proportions that some measures to reduce them became imperative. It was already quite clear that any effective measures must be based upon accurate and voluminous data on the characteristics of equipment and protective devices.

The wide variety of insulation in use, together with little knowledge of the actual performance of various types of arrester, made it impossible to hope for an effective improvement program based upon data furnished by electrical equipment manufacturers. It was believed that only a comprehensive and fundamental attack would suffice, and in January 1932, a surge generator and cathode-ray oscillograph were installed in the high-voltage laboratory of the company.

Laboratory Tests

Kilovolt-time breakdown curves have been obtained for almost every insulation element of the system which is susceptible of such a measure. If a curve was not feasible, as in the case of transformers, minimum breakdown values have been ascertained which serve as approximate guides when considered with other data.

The characteristics of lightning arresters have been extensively studied in relation to the breakdown curves of the equipment to be protected.

Figure 1 illustrates typical laboratory tests to obtain these data. The arrester performance shown by the volt-time and volt-ampere oscillograms is representative of approximately 60 per cent of the arrester protection in service prior to 1932,

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1. For all numbered references, see list at end of paper.

and reference to this performance will be made in the discussion which follows.

An important addition to these somewhat standardized tests was the devising and testing of methods to increase the strength of system elements which could not be replaced except at prohibitive cost.

Field Tests

The portability of the surge generator and cathode-ray oscillograph made it possible to test substations as a whole to determine points of maximum voltage caused by reflections, and to detect unsuspected weak insulation. Lightning arresters in service were tested—sometimes with startling results. In still other tests, bus and disconnect-switch insulators were flashed over, with no regard to the shape of the applied surge, and the results compared with those predicted by laboratory impulse breakdown curves. The upper curve of figure 2*a* shows a kilovolt time-lag curve of a two-unit pedestal insulator obtained in the laboratory. The lower curve is a replot of oscillogram 55-7, with zero time corresponding to the crest value of the 60-cycle breakdown, and is the record of the flashover of the same type of pedestal insulator installed on the bus of a transmission substation.

Figure 2*b* shows a volt-time oscillogram of an arrester taken immediately after de-energizing it for field tests.

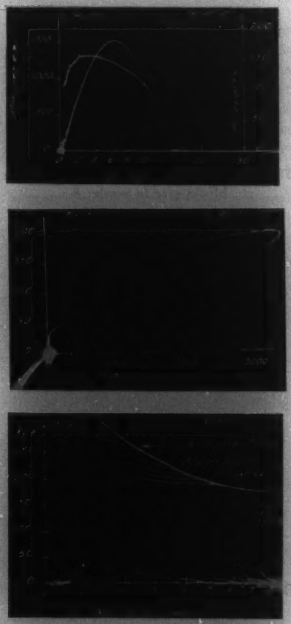

Figure 1. Typical laboratory tests
Oscillogram C45-3-4—25-kv arrester
Oscillogram C19-7—34.5-kv disconnect switch

Application of Data to System Improvement

When a cross section of the system insulation had been obtained, it became apparent that much of the indoor insulation was not protected by the arresters installed, at a moderate discharge current. Circuit breakers, disconnect switches, bus insulators, transformer bushings, and even some current transformer bushings and windings were found to have minimum impulse strength in the range from 100 kv to 150 kv.

A survey of all 22-kv indoor stations revealed that a basic level of 150 kv could be established by rebuilding certain types of circuit-breaker bushings, replacing bus and disconnect-switch insulators of low strength, and eliminating some obsolete equipment entirely.

Fortunately, the most widely used indoor disconnecting switch had a minimum breakdown of 150 kv, and this value was chosen as the minimum for all acceptable insulation. In some substations, special measures were required to bring the strength above the minimum set.

Figure 3 illustrates the relation between the arrester and typical kilovolt-time curves of insulation. Although curves are shown for a disconnect switch and three different circuit-breaker bushings, many other insulation elements would practically duplicate these curves.

Three types of circuit breaker were equipped with a bushing composed of an outer corrugated porcelain tube, an inner "Micarta" tube extending above and below the procelain, and a copper stud of much smaller diameter. The air space between the stud and tube was easily overstressed, and puncture of the Micarta tube followed by air flashover from the top of the porcelain to the circuit breaker operating mechanism was common. This defect was remedied by filling the air space with another close-fitting Micarta tube and increasing the length of the external portion of both tubes.

Other circuit-breaker bushings could neither be lengthened nor replaced, except at an unwarranted cost. In such cases the connection to the bushing was heavily taped, great care being exercised to exclude air pockets. Tests indicated

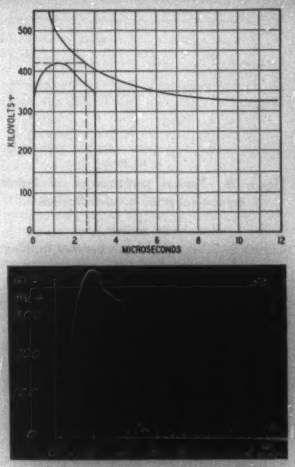

Figure 2a. Comparison of field test flashover with laboratory curve

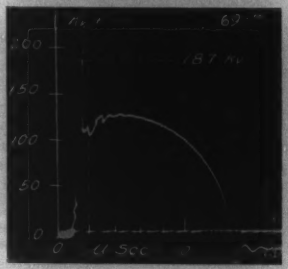

Figure 2b. Field test on 25-kv arrester, first impulse

that this expedient increased the impulse strength well above the basic level.

A great many transformer bushings possessed sufficient strength external to the transformer tank, but were very weak internally because of low air or oil surface clearances between the lead and the tank. Other bushings were adequate internally but were very weak externally. To solve this problem and reduce bushing stocks, a one-piece porcelain bushing was developed having adequate impulse strength externally and which extended below the oil level in all transformers. By means of flange adapters one bushing was made applicable to transformers of different manufacture.

In one station, subject to numerous bus failures, the entire bus of bare copper was removed and replaced with 22-kv varnished-cambric insulated wire. To avoid taped joints within the small com-

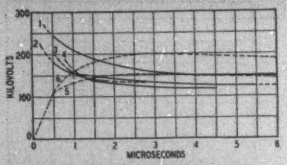

Figure 3. Typical performance of indoor equipment prior to co-ordination

Curve 1—Disconnect switch
Curves 2, 3, 4—Oil-circuit-breaker bushings
Curve 5—Arrester, 1,500 amperes in six microseconds
Curve 6—Arrester, 3,250 amperes in six microseconds

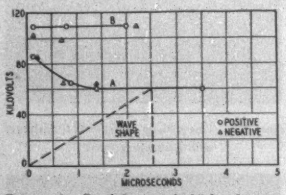

Figure 4. Breakdown of 25-kv line-type arresters

partment which would lower the impulse strength, the bus was run to each disconnect switch and then back to the compartment. The switch was at the basic level of 150 kv, and the bus much higher.

Figure 3 shows clearly that the basic level of 150 kv could not reliably be protected by the arrester whose performance is indicated. Further, insulation levels as high as 200 kv were endangered when the arrester discharge current exceeded 3,000 amperes. A general replacement program was necessary to establish system-wide arrester performance under the basic level.

Several designs of station and line-type arrester were critically tested, and from the results it was concluded that the protection provided by station type arresters was not sufficiently greater than that provided by line-type units to justify the greatly increased cost.

Two line-type units were decided upon and the replacement program begun. Figure 4 shows positive and negative break-down data on the two arresters *A* and *B*. Figure 5 shows a high current test on one of five impedance blocks used in the 25-kv arrester *A*.

Figure 6 illustrates the co-ordination of equipment insulation and the arrester performance for both light and heavy discharges. It is apparent that the maximum impedance drop of arrester *A* depends primarily on the rate of increase of discharge current, while that of arrester *B* depends upon the maximum magnitude of the discharge current. Laboratory tests and field experience indicate that the solid line curves are near the maximum voltages which the insulation of the arresters themselves will support, for the arrester is destroyed before curve 1 is reached.

In an attempt to obtain some idea of the winding strength of 22-kv transformers, a 667-kva single-phase 22-kv to 2.3-kv transformer was tested to breakdown with the results given in figure 7. Oscillogram 98-1 shows three full waves applied without a winding breakdown. Oscillogram 98-4 shows two winding breakdowns. The first winding breakdown occurred at an applied voltage of 210 kv on another test intermediate between those shown. The rarity of transformer failures makes it probable that the actual strength of most of the transformers is near 200 kv.

Since the outset of the co-ordination program, 408 circuit-breaker bushings, 388 transformer bushings, and 342 new arrester units have been installed. Numerous changes of other equipment and insulation have also been necessary to achieve impulse strength equal to or above the basic level.

System Performance After Improvements

Two methods were adopted to maintain as close a check as possible on the efficacy of the co-ordination program. The first of these was a systematic investigation of each individual station fault caused by lightning, and accurate recording of all line, cable, and station equipment faults during thunderstorms. The second method involved the selection of 13 stations notable for frequent lightning failures prior to the improvements, and the installation of lightning-arrester operation counters in these stations. This group is well scattered about the system and is thought to be a fairly representative sample. The operation recorder developed was energized by the current through the arrester, and it counted each distinct discharge.

Figure 8 gives index numbers for the total 22-kv line, cable, and station equipment faults; the station equipment faults alone; the station faults in per cent of the total faults; and the number of arrester operations recorded in the sample group of stations. To facilitate comparison of the first two data, the average of the 1930 and 1931 figures has been taken as 100. For the arrester operations, the average number of operations per year has been taken as 100. The correspondence between arrester operations and total faults merely reflects the fact that the number of surges which are virtually certain to exceed the basic station kilovolt level is proportional to the number of surges exceeding the line insulation at the point of origin. This conclusion is believed justified by the further facts that the average length of overhead line between stations is approximately two miles, and the line insulation ranges from a minimum of about 300 kv to over 1,000 kv. In this connection it is also well to remember that direct strokes to the line causing flashover to ground within a few spans of the station will result in voltages limited by the stroke current and the structure ground resistance, rather than by the structure insulation alone.

Although the impulse testing of equipment and arresters was begun in 1932, a number of arrester replacements and insulation improvements put into effect in 1931 were confirmed by the tests, and their influence on system performance is

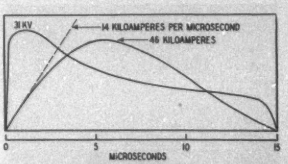

Figure 5. High-current test on one of five blocks used in arrester A

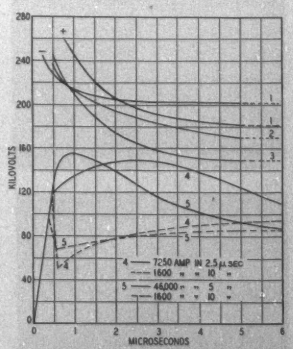

Figure 6. Typical co-ordination of indoor equipment after improvements

Curve 1—Transformer bushing
Curve 2—Oil-circuit-breaker bushing
Curve 3—Disconnect switch
Curve 4—Arrester *B*
Curve 5—Arrester *A*

shown in figure 8. Despite the fact that a slight increase in the actual number of station faults occurred in 1931, the weighed index giving these faults in per cent of total shows a decided drop.

In 1934 and 1935 the work was largely directed toward 66-kv transmission substation problems and 4-kv equipment protection, and this divergence is strikingly revealed by the index numbers. Again, further 22-kv improvements were put into effect late in 1935, and the 1936 record was still better.

Conclusions

The widely varying conditions encountered on subtransmission systems make it difficult to generalize the results of this program in any valid manner. The co-ordination of insulation and arresters has been in accordance with the present recommended basic level of 150 kv. Considerations of cost and space limitations dictated the choice of this level at the beginning of the co-ordination program in 1932, and the result of five years' operating experience are given in this paper. For systems having insulation and arrester performance whose relation to the basic level is comparable to that of figures 1 and 3, and whose exposure to surges is of the same degree as that cited, one may anticipate that similar improvement in performance will accompany co-ordination based upon detailed knowledge of insulation and arrester characteristics.

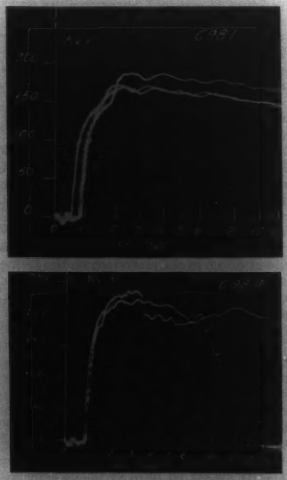

Figure 7. Winding breakdown tests on a 667-kva 22-kv to 2.3-kv transformer

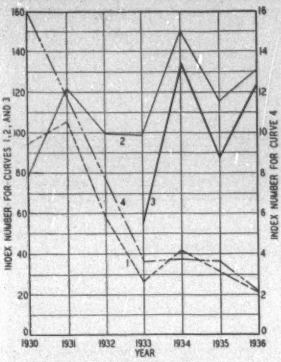

Figure 8. Lightning faults on 22-kv system

Curve 1—Station equipment faults
Curve 2—Total 22-kv faults
Curve 3—Station arrester operations
Curve 4—Station faults as per cent of total faults

Acknowledgments

The author wishes to express his appreciation of the liberal company policy which has made possible a fundamental attack on the lightning problem.

Particular acknowledgment is made of the work of Mr. D. B. Perrin who has been closely associated with the author throughout this work.

Mr. H. H. Marsh, Jr. has furthered the program by his interest in and appreciation of many problems of detail, and has been especially helpful in the preparation of the paper.

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Discussion

E. J. Allen (General Electric Company, Pittsfield, Mass.): This paper illustrates the practical benefits resulting from a comprehensive program of insulation co-ordination and protection. One of the most significant of these benefits is the great reduction in station faults caused by lightning in per cent of the total faults, after the co-ordination program was well under way in 1933. Figure 8 of the paper shows that although the total faults caused by lightning on the 22-kv system were higher in 1934 and 1936 than any other year since 1929, the percentage of station faults due to lightning has been steadily decreasing.

The choice of 150 kv as a basic impulse insulation level in 1932 for station equipment on this 22-kv system is the same as that more recently published by the EEI-NEMA Joint Committee.[1] As this paper concerns line-type lightning arresters, it is of timely interest to note the line-type lightning-arrester performance data[2] presented by the lightning arrester subcommittee. This report shows that the average impulse protective characteristics afforded by new designs of 25-kv line-type lightning arresters is less than 100 kv crest—representing over 50 per cent margin of protection to the 150-kv basic impulse insulation level.

Figure 1 of this discussion shows volt-time and ampere-time oscillograms taken on modern 25-kv Thyrite line-type lightning arresters at discharge currents of 1,790 and 5,600 crest amperes.

Figure 2 shows the general appearance of this type of arrester; employing unit type construction and containing Thyrite-shunted gaps and the main Thyrite valve element disks in the same housing. The impulse tests shown in figure 1 were obtained from a 25-kv arrester of the type shown second from the left-hand side of figure 2.

Calculations indicate that the maximum impulse wave of a 1,000-kv crest passed by the line insulation described by the author results in a lightning-arrester discharge current approximately 3,800 amperes at the line terminals, assuming 500-ohm line surge impedance. This seems to indicate that lightning-arrester discharge currents in service, except for possibly chopped waves resulting from direct lightning strokes contacting the line at a point close to the station, are well within the range of discharge currents up to 5,000 amperes, as set forth in the report of the lightning arrester subcommittee. Moreover, Messrs. McEachron and McMorris[3] have summarized the data in regard to lightning-discharge currents through lightning arresters located on primary distribution circuits rated 2,400 to 24,000 volts. These data show that 90 per cent of the discharge currents measured through lightning arresters are 5,000 amperes or less. These data apparently show that approximately 25 years may be expected to elapse for each discharge of at least 5,000 amperes through any one arrester.

Previous experience, together with the results shown in this paper, demonstrates the benefits resulting from a fundamental attack on the lightning problem. It is uneconomical and impractical to build into the connected apparatus sufficient insulation strength to withstand unmodified lightning voltage in service. Hence, lightning arresters affording ample margin of protection to apparatus insulation are the established economical basis of system co-ordination and protection.

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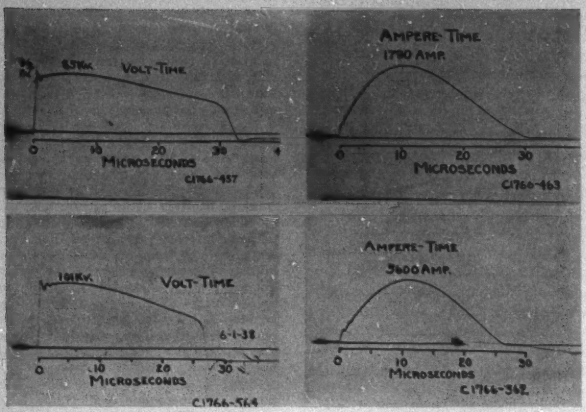

Figure 1. Impulse protective characteristics, Thyrite line-type lightning arrester, maximum rated 25 kv

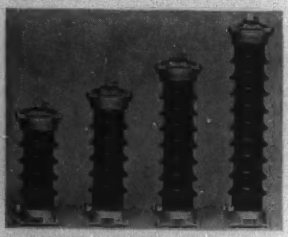

Figure 2. Thyrite line-type lightning arresters, maximum rated 20, 25, 30, and 37 kv, respectively

Co-ordination. ELECTRICAL ENGINEERING, volume 56, June 1937, page 711.

2. LINE TYPE LIGHTNING ARRESTER PERFORMANCE DATA, lightning arrester subcommittee. Summer convention, 1938, AIEE Technical Paper 38-56.

3. DISCHARGE CURRENTS IN DISTRIBUTION ARRESTERS—II, E. B. McEachron and W. A. McMorris. AIEE TRANSACTIONS, June 1938, volume 57, pages 307–12.

P. L. Bellaschi (Westinghouse Electric and Manufacturing Company, Sharon, Pa.): Mr. Whitehead's paper presents a fine example of the application of insulation co-ordination, where it was thoroughly planned and well carried out to provide improved protection to 22-kv substations. At the time this work was initiated, impulse data on installed apparatus were rather meager. The wisdom, therefore, in using an impulse generator from the start is fully apparent from the results that have been achieved.

A point of particular interest is that Mr. Whitehead, starting out in 1932 in his co-ordination work, arrived after certain tests and analysis, to the conclusion that 150 kv for the 22-kv substations was a sound impulse insulation level to aim for. This is also the figure now prescribed by the EEI-NEMA Joint Committee on System Insulation Co-ordination. The coincidence is not, however, accidental since the processes in arriving at the levels are basically the same.

Figure 6 of the paper which shows the apparatus voltage-time curves (1, 2, and 3) of the substation apparatus above the established level and the characteristics of the protective devices below the level (curves 4 and 5) tell a very significant story of the technical and economic problems that had to be overcome to establish the 150-kv level. They also illustrate the principles in general on which the present insulation levels have been arrived and are based.

As stated in the paper, the insulation of the 22-kv lines ranges from 300 kv to over 1,000 kv. Presumably these low-voltage lines are not equipped with overhead ground wire. It is now quite well established from the field investigations here and abroad that the induced voltages seldom exceed 300 kv and from this consideration it then appears that the larger percentage of the impulse voltages entering the substation originate from direct strokes to the line.

Since there are two miles of line between two stations on the average, half of the strokes will travel one-half mile before entering a substation and therefore their severity would be attenuated somewhat. That the author has given consideration to direct strokes is clearly apparent from the arrester characteristics for high current discharges taken into consideration in figure 6. It would be of interest to have an expression of view from the author as to what extent direct strokes in the station or within one or two spans of the station represent the per cent of substation faults shown in figure 8 and what further measures are being considered to protect the substations against direct strokes.

J. T. Lusignan, Jr. (Ohio Brass Company, Mansfield): The author has described a fine example of a rather thorough insulation co-ordination program. The fact that it was possible to bring the surge generator and oscillograph to the substations in order to check the transient voltages there and the actual insulation provided to handle them is surely a fortunate circumstance. It is interesting to find, at least from the one example he shows (figure 2a), how well his measured insulator voltage values agree with the laboratory curve.

I find no mention of polarity in so far as flashover values are concerned. In insulation co-ordination the question often arises as to whether co-ordination should be on the basis of positive values only or both positive and negative values. I believe that field records show most severe direct strokes to be of negative polarity although many of the lower voltage lightning strokes are positive. If the stroke occurs to the conductor a surge of the same polarity obviously is imposed upon the insulation. A stroke to the ground wire or other nearby grounded object, of course, induces a surge of the opposite polarity upon the conductors. I am wondering what consideration Mr. Whitehead has given to this. For 22-kv insulators the positive and negative flashover values are often practically equal whether base or cap mounted. However, I am wondering whether there are other insulation breakdown points in a station which will exhibit sufficient polarity characteristics to warrant the latter being considered.

E. R. Whitehead: Mr. Allen presents performance data on the newly developed Thyrite distribution-type arrester. This line, of selected unit construction, appears to offer new possibilities for economy and flexibility in equipment protection.

The characteristics of the modern distribution-type arrester viewed in relation to the basic impulse levels and the McEachron-McMorris current distribution curves should provide a sound basis for their application.

Mr. Bellaschi raises a point of considerable interest. Prior to the co-ordination program it was not uncommon for weak station equipment to flash over during thunderstorms without an accompanying line fault. A combination of poor co-ordination and induced surges seems to explain this type of fault.

During the period covered by the paper, there has been a considerable increase in the use of wood crossarm braces and guy insulators. As a consequence most substation faults now correlate with direct-stroke line damage such as splintered braces, arms, or guys located within a very few spans of the station. The large number of stations involved in relation to the very small number of substation faults precludes any general use of direct-stroke protection on the 22-kv system. Consideration is now being given to auxiliary current-limiting schemes such as expulsion tubes or gaps one span from the station at the most exposed locations.

Doctor Lusignan asks what consideration has been given to polarity in the co-ordination studies. At the outset of the program it was essential to cover as many system elements as possible in a short time in order that early application of the data might be made. Positive-polarity time-lag curves were found to be lower than negative-polarity curves for most of the equipment, and therefore the earlier work was largely done with the former. In the later stages of the program both polarities were used.

Tests on Oil-Impregnated Paper—III

Fluid Flow

By HUBERT H. RACE
MEMBER AIEE

I. Introduction

IN TWO previous papers[1,2] we have described some of the results of life-test studies of miniature cable specimens started in 1934. One of the general observations resulting from a large number of tests is that all specimens made with high-density paper and standard-viscosity oil or specimens made with standard-density paper and high-viscosity oil have had short life at 30 kv whereas many specimens made with standard viscosity impregnant but otherwise identical have had very long life under the same conditions.

In attempting to explain these results we made the hypothesis that with either high-density paper or high-viscosity impregnant, the rate of flow of the impregnant through the paper during the cooling portion of the daily heat cycle was not great enough to prevent void formation. This would then result in ionization and early failure. We had all the data necessary to check this hypothesis except the flow characteristics of oil through paper. A search of the literature revealed little pertinent information although a considerable amount of work has been reported on the permeability of paper and other materials to air. A summary of this work and a bibliography of 31 references is given by Carson.[3] It is characteristic of all the work done on paper that the pressure head on the paper does not exceed a few centimeters of mercury and in Carson's work was limited to five to ten centimeters of water. This is due, of course, to trouble from deformation of unsupported sheets of paper at the higher pressures and also to certain convenient methods utilizing low heads. Goldberg performed some experiments of this type but neglected to take account of the expansion of the air as it passes through the paper. He noticed deviations at higher pressures and attributed these to turbulence, which is probably incorrect since we have used much higher rates of flow without turbulence. It also appears that his apparatus is subject to leakage, which can cause large errors.

A number of workers have investigated the flow of liquids through porous media.[5-16] Some of these have found anomalous results, which our preliminary work indicates was caused by the fact that the liquids used were not gas free. When the liquid contains gas, part of it comes out of solution as the pressure decreases, causing gas pockets in the paper, which decrease the rate of flow. This agrees with the work of Muskat[12] on mixtures of gas and oil flowing through sands although the latter work indicates other effects besides the formation of gas pockets. The only work we have found related to the flow of oil through paper is that of Whitehead and Greenfield,[17] relying on capillarity to produce the flow. However, we are not so much concerned with the flow in the plane of the paper as in the flow through it under hydraulic pressure.

Apparently few comparative studies have been made with different fluids on the same porous medium. Bull and Wronski[11] have made a comparative study with seven alcohols, carbon tetrachloride, and water in cellulose, glass, and carbon diaphragms with the interesting conclusion that the viscosity of the liquid was not the only property of the liquid important in determining the flow. No experiments at all have been reported, so far as we can determine, which give direct comparison between gas and liquid flow.

This paper gives the results of such a direct comparison together with studies of oil flow under varying conditions and the application of these data in determining limiting conditions causing void formation in cables.

II. Flow Equations

The flow of fluids through porous media can be expressed by Darcy's law (see reference 12),

$$v = (-K/\eta)\nabla p \qquad (1)$$

where v is the vector rate of flow of the fluid, p the fluid pressure, η the viscosity of the fluid, and K a coefficient which has been called the "permeability" or flow constant of the porous medium. K may accordingly be defined as the volume of a homogeneous fluid of unit viscosity passing through a unit area in unit time under the influence of unit pressure gradient.

A. Flow of Oil Through Paper

In our experiments flat sheets of paper were used and the lines of flow through the test area A were everywhere normal to the paper. Consequently, the general flow equation 1 may be written in the one-dimensional form:

$$v_x = (-K/\eta)\, dp/dx \qquad (2)$$

In this case $v_x = Q/A$ where Q is the rate of flow of oil in cubic centimeters per second through the test area (A in square centimeters). Therefore,

$$Q = -(KA/\eta)(dp/dx) \qquad (3)$$

For steady state, with constant pressure difference and constant time rate of flow

$$dp/dx = -(p_1 - p_2)/NL \qquad (4)$$

where p_1 and p_2 are the inlet and outlet pressures in dynes per square centimeter, N is the number of layers of paper, and L is the thickness of one layer of paper in centimeters. Then

$$K = (Q/A)(\eta NL)/(p_1 - p_2) \qquad (5)$$

(η is in poises, that is, dynes times seconds divided by square centimeters, and K has the dimensions of an area).

B. Flow of Gases Through Paper

In dealing with the flow of gases through porous media, we may still use Darcy's law, and since the geometrical

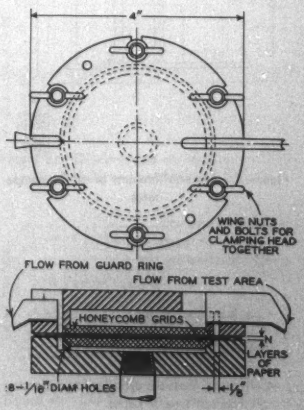

Figure 1. Oil-flow head

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1. For all numbered references, see list at end of paper.

features of our gas- and oil-flow apparatus are the same, equation 3 will also apply to gas flow. Due to the expansion of the gas as it passes to a region of lower pressure, it is convenient to express this relation in terms of the mass of gas flowing per second which we will call M. Then since

$$M = \rho Q \tag{6}$$

where ρ is the density, we have from equation 3

$$M = -(KA\rho/\eta)(dp/dx) \tag{7}$$

For gas flow dp/dx varies with x so that (7) will have to be integrated. In order to do this we assume Boyle's law to hold so that ρ/p is a constant, the temperature being assumed constant. The ratio may be taken at any condition (a), say at one atmosphere as a matter of convenience. Thus

$$\int_0^{NL} M dx = -\frac{KA}{\eta}\left(\frac{\rho_a}{p_a}\right)\int_{p_1}^{p_2} p\,dp$$

Integrating and rearranging we have

$$M = (KA/2\eta NL)(\rho_a/p_a)(p_1^2 - p_2^2) \tag{8}$$

The determination of M can be made by direct measurement or by using a calibrated capillary. We have used the latter by allowing the gas to flow directly through the capillary after it leaves the measuring section of the paper. Consequently M is the same for the paper and the capillary. M may be determined for the capillary by the method described in Barr's "Monograph of Viscosity."[13] Although a radial component flow exists in the case of a gas flowing through a capillary, it has been found that Poiseuille's law of flow, which holds when the flow is strictly laminar, can be used if the rate of change of density with length is not too great.[18] This condition is realized in a long capillary of a fairly large diameter. Poiseuille's law is:

$$Q = -(\pi r^4/8\eta)(dp/dl) \tag{9}$$

where r is the radius of the capillary, dl is an element of length, η the viscosity of the gas. As in equation 7 we replace Q by M/ρ

$$M = -(\pi r^4/8\eta)(\rho/p)\,p\,(dp/dl) \tag{10}$$

and assume that the gas expands according to Boyle's law in passing through the capillary. Integrating (10)

$$\int_0^l M dl = -\frac{\pi r^4}{8\eta}\left(\frac{p_a}{p_a}\right)\int_{p_1}^{p_a} p\,dp$$

$$M = (\pi r^4/16\eta l)(\rho_a/p_a)(p_1^2 - p_a^2) \tag{11}$$

Here η has been assumed to be independent of pressure as it is within wide limits (see reference 18 and also volume V of International Critical Tables, page 2). p_2 is the same as in (8) and p_a is the outlet pressure of the capillary (atmospheric in our apparatus). (ρ/p) is the same as in (8).

Equation 11 holds fairly well for rough measurements, but for accurate work it must be corrected for kinetic energy of the gas, end effects, slip and so on (see reference 18). The kinetic-energy correction is by far the largest correction; therefore, neglecting the others, equation 11 becomes

$$M = (\pi r^4/16\eta l)(\rho_a/p_a)(p_1^2 - p_a^2) - (1.1\,M^2/8\pi\eta l) \tag{12}$$

K can now be calculated by eliminating M from equations 8 and 12.

Before this can be carried out numerically it is necessary to calibrate the capillary, that is, determine the factor $(\pi r^4/8l)$; l can be measured directly (33.8 centimeters in our case), but r, the radius, is not determined so easily. The usual practice is to partially fill the capillary with a thread of mercury, measure its length, weigh it, and from the density, weight, and length, determine its volume and from that the radius r. One may also test the uniformity of the bore by observing the length of the thread at various positions along the capillary.

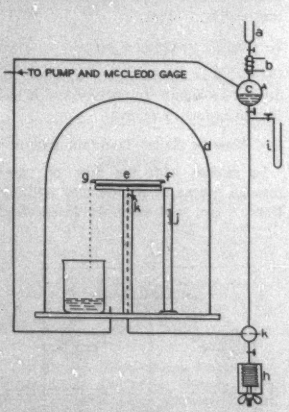

Figure 2. Essential features of oil-flow apparatus

a—Filling reservoir
b—Heater for degasifying oil
c—Oil level during test
d—Bell jar
e—Head
f—Overflow for test area
g—Overflow for guard ring
h—Sylphon bellows
i—Mercury manometer
j—Calibrated graduate cylinder for collecting oil from test area of paper
k—Thermocouple leads

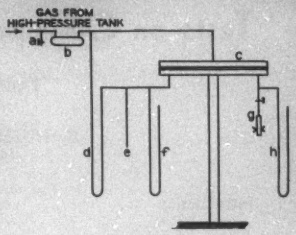

Figure 3. Essential features of gas-flow apparatus

a—Stop cock for regulating pressure
b—Phosphorus-pentoxide drying tube
c—Head
d—Differential manometer for measuring head across test area of paper
e—Capillary
f—Manometer for measuring head across capillary
g—Stop and pinch cock arrangement for regulating head across guard area of paper
h—Manometer for guard area of paper

Table I. Properties of Papers M and N

Property	M	N	Ratio M/N
Type	Kraft	Kraft	
Apparent density	0.75	1.10	0.68
Tensile strength (pounds per one-inch strip)			
Lengthwise	90	81	1.11
Crosswise	36	32	1.12
Per cent elongation			
Lengthwise	2.9	2.2	1.32
Crosswise	7.8	9.9	0.79
Tearing strength (grams, Elmendorf)			
Lengthwise	189	229	0.82
Crosswise	235	293	0.80
Per cent ash	0.56	0.52	
Alkalinity (milligrams of sulphuric acid per gram)	0.118	0.090	
Air resistance (seconds per mil, Gurley)	21	318	0.066 (Ratio N/M = 15.1)
Permeability K ($\times 10^{-12}$)			
Gas (N_2)	12.5	0.92	13.6
Liquid (oil A)	12.5	0.59	21.2

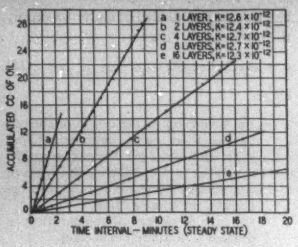
a 1 LAYER, K=12.8 x 10⁻¹²
b 2 LAYERS, K=12.4 x 10⁻¹²
c 4 LAYERS, K=12.7 x 10⁻¹²
d 8 LAYERS, K=12.7 x 10⁻¹²
e 16 LAYERS, K=12.3 x 10⁻¹²
ACCUMULATED CC OF OIL
TIME INTERVAL—MINUTES (STEADY STATE)

Figure 4. Oil-flow data on standard-density paper (M) for various numbers of layers

Our best determination of r^4 by this method was

$r^4 = 70.8 \times 10^{-8}$ centimeters^4

In using a capillary, care must be taken not to use such high rates of flow that turbulence occurs. The condition that the flow is not turbulent is that $R = \rho V d/\eta \leq 2{,}000$ (Reynolds' criterion. See International Critical Tables, volume V, page 2; also reference 19). Here ρ is the density, V linear velocity, η viscosity, d bore of capillary. For our capillary and our largest rate of flow R is about 35 so that we are working well below turbulent flow.

The question of turbulence may also be raised in connection with the paper. Here the bore diameters are all much smaller than that of the capillary and the linear velocity is also less than for the capillary. This means that R will be less than for the capillary and that turbulence cannot occur in the paper if it does not in the capillary.

In the calculations below, we use $(\pi r^4/16l) = 41.2 \times 10^{-10}$, $l = 33.8$ centimeters, and wherever $(p_a^2 - p_b^2)/p$ occurs multiply by $980.3 \times 13.53 = 1.328 \times 10^4$ (13.53 is the density of mercury to four places from 24.5 to 28.5 degrees centigrade) so that it is not necessary to convert pressures from centimeters of mercury to dynes per square centimeter. $A = 52.4$ centimeters. Then equation 12 becomes

$$M = 5.46 \times 10^{-4}(\rho_a/p_a)(p_2^2 - p_a^2) - 1.297 \times 10^{-3}M^2/\eta \quad (13)$$

and (8) is

$$K = 2.88 \times 10^{-4}\, NLM\eta p_a/p_a(p_1^2 - p_2^2) \quad (14)$$

III. Apparatus for Measuring Gas and Liquid Flow

The same geometrical arrangement has been used in both the gas-flow and oil-flow experiments. In both cases we wished to obtain data with pressure differences up to one atmosphere so that it was necessary to use supporting grids to prevent deformation of the paper under pressure. Although this introduces some uncertainty in the calculated area of flow, we assume that this does not affect the relative values of the gas and oil flow permeabilities. In all our calculations we have used the total area covered by the test section of the supporting grid.

In both the oil- and gas-flow experiments the paper was tightly clamped between the two halves of a device which we have called a head. Both heads are essentially the same, and the design of the oil-flow head is shown in figure 1. The test area is that area occupied by the honeycomb grids and it is the rate of flow through this area that comprises Q. In order to assure flow normal to the test area, a guard ring was provided in each case which had the same pressure drop across it as the test area. If the leakage through the edges is not too great this is an entirely satisfactory arrangement. Excessive leakage may be controlled by coating the edges of the paper with a plastic material which does not penetrate the test section. We used an air drying plastic Glyptal quite satisfactorily.

Figure 2 is a schematic diagram of the oil-flow apparatus. The apparatus is assembled as shown and thoroughly evacuated for several hours at a pressure of about one micron or less. The oil is introduced into the filling reservoir a, is allowed to trickle slowly through the heater b and into the bulb. This degasifies the oil. The oil was allowed to flow in at such a rate that the pressure of the system never exceeded about 25 microns. During the filling period the sylphon bellows was fully extended by means of the wing nut. The system was filled with oil up to a level c. The stopcock below c was then closed and the sylphon h released by loosening the wing nut. This puts approximately one atmosphere hydraulic pressure on the high-pressure side of the paper. The lower pressure is about 0.5 centimeter of oil plus the gas pressure, which was kept at about 0.1 micron throughout the tests. The oil from the test area flowed from f into the graduate j. The rate of flow was measured with an accurate stop watch and carefully calibrated graduate cylinder. In practice the manometer i was below the head so that the column of oil between the upper mercury level and the level of the paper had to be taken into account in calculating the pressure p_2.

The gas-flow head differs from figure 1 only in that pipe connections to the rest of the setup were used instead of overflow spouts. The arrangement of the gas-flow apparatus is shown schematically in figure 3; h is the manometer measuring the pressure above atmospheric of the guard area on the low-pressure side. Since the pressure on the top side of the paper is the same for both the guard area and the test area, the pressure drop across the guard area may be made equal to that across the test area by making the manometer reading Δh_1, of the guard manometer equal the reading Δh_2 of manometer f. This is done by bleeding off gas at g, which can be done only if there is not too much leakage at the edges of the paper.

If Δh_3 is the reading on manometer d, the pressures are as follows: $p_2 = p_a + \Delta h_2$, $p_1 = p_a + \Delta h_2 + \Delta h_3$. K can then be calculated from equations 12 and 8.

The gas for the gas-flow experiments was supplied by a tank of nitrogen at about 1,500 pounds per square inch pressure with a suitable reducing valve.

IV. Flow Data and Values of K

A. Oil Flow

The physical properties of the two grades of cable paper used are given in table I. The data and calculations for the oil-flow experiments are shown in table II. The slopes of the curves shown in figures 4, 5, and 6 are equal to Q for each of the indicated cases. Two or more runs on the same thickness of paper will not necessarily give the same rate of flow Q due to differences in viscosity and density of oil, which vary with temperature, and also to the variation of atmospheric pressure from run to run. This is illustrated in curves (a) and (b) of figure

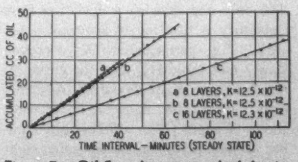
ACCUMULATED CC OF OIL
a 8 LAYERS, K=12.5 x 10⁻¹²
b 8 LAYERS, K=12.5 x 10⁻¹²
c 16 LAYERS, K=12.3 x 10⁻¹²
TIME INTERVAL—MINUTES (STEADY STATE)

Figure 5. Oil-flow data on standard-density paper (M) for various numbers of layers

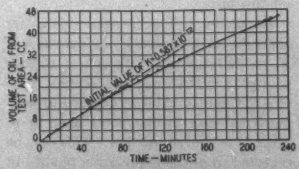

Figure 6. Oil-flow data, one sheet high-density cable paper (N)

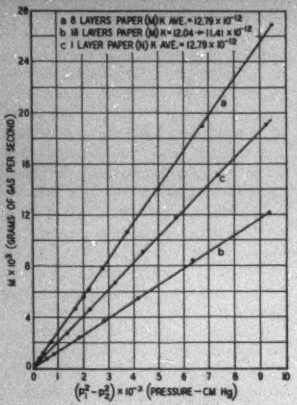
a 8 LAYERS PAPER (M) K AVE. = 12.79 x 10⁻¹²
b 16 LAYERS PAPER (M) K = 12.04 → 11.41 x 10⁻¹²
c 1 LAYER PAPER (N) K AVE. = 12.79 x 10⁻¹²
M x 10⁵ (GRAMS OF GAS PER SECOND)
(p₁² − p₂²) x 10⁻³ (PRESSURE − CM Hg)

Figure 7. Flow of N_2 through cable paper

5, which give the same value for K although the slopes of the curves are somewhat different. For the same reason the slope of the curve for eight layers will probably not be exactly twice that for four layers [(*c*) and (*d*) of figure 4].

The value of K in table II for paper (N) was calculated for the first seven points of the curve (figure 6), which are sensibly a straight line ($K = 0.587 \times 10^{-13}$). From then on the rate of flow decreased, indicating the possibility of some slow swelling or rearrangement of the fibers in this highly calendered paper.

B. Gas Flow

The data for these tests are in table III and figure 7 shows plots of the mass rate of flow M versus $(p_1^2 - p_2^2)$, which should be straight lines if K is a constant. The only one showing a deviation from constancy is that for 16 layers of paper (M). The permeability K decreases slowly (see table III), but the curve (*b*) shows only a slight deviation from linearity. Curve (*a*), figure 7, is for eight sheets of paper (M). Oil-flow test number 6 was made on these same eight sheets after taking the gas-flow data. Similarly, curve (*c*) is for the same sheet of paper (N) that was used later in the oil-flow test.

Discussion. The gas-flow data for eight sheets of paper (M) give a value of $K = 12.79 \times 10^{-13}$, which is slightly greater than the value from oil-flow data. It is not unreasonable to expect this inasmuch as some of the pores may be so small as to prevent oil flow. This may be expected from the appreciable rigidity of very thin layers of liquids. We are inclined to believe that the lower value of K obtained for 16 layers and the regular variations are not real but may be due to leakage through the edges. This is possible for a thick test specimen even when the guard ring has the same pressure drop as the test area. Moreover, examination of the formulas indicates that the calculated value of K will be reduced by such leaks.

In the high-density paper the resistance to gas flow was roughly 14 times greater than in the low-density paper whereas the resistance to oil flow was initially 21 times greater than in the low-density paper. (See table I.)

While the average density of the high-density paper (N) is only about 40 per cent greater than for the standard density paper (M), the process of manufacture of the former gives it surface layers of very closely packed fibers so that the major resistance to fluid flow is in these surface layers, thus explaining the relatively large effect on flow characteristics.

It should be noted that the above relations and results are for steady-state conditions only and are not expected to hold either when the paper is only partially saturated or when the liquid contains gases in solution or materials that will be adsorbed or filtered out by the paper, thus decreasing the effective capillary area.

V. Application of Flow Data to Conditions for Void Formation in Gas-Free Cables

A. Assumptions

In studying the application of these data to the problem of void formation in cables we shall assume the following conditions:

1. The partial pressure of gas in the paper and impregnant is negligible, that is, the cable is virtually gas free.
2. The core dose not act as an oil reservoir so that during cooling all the impregnant required to keep the paper full must flow in from the outside.
3. The flow is radial, no longitudinal flow in the paper being considered.
4. Contraction of the paper fibers themselves is negligible.
5. A sufficient reservoir of impregnant is maintained on the outside circumference of the paper.

B. Hydraulic Pressure Necessary to Keep Paper Full

Let figure 8 represent the cross section of a cable in which we wish to determine the hydraulic pressure necessary to keep the interstices of the paper full of impregnant during cooling by uniform radial flow from the outside.

Let q = the total flow per centimeter length into the shaded cylinder to supply the interstices. Then

$$q = \pi\sigma s C(r^2 - r_1^2) \qquad (15)$$

where

σ = the coefficient of expansion of the impregnant in cubic centimeters per cubic centimeter per degree centigrade.
s = the space factor, that is, the ratio of the volume occupied by the impregnant to the total volume.
C = the rate of change of temperature in degrees centigrade per second.
r = radius in centimeters.

Then if V_r = the radial velocity of flow we have

$$V_r = -q/2\pi r = -\sigma s C[(r/2) - (r_1^2/2r)] \qquad (16)$$

Also, Darcy's law stated in radial coordinates gives

$$V_r = -(K/\eta)(dp/dr) \qquad (17)$$

Then eliminating V_r we have

$$(dp/dr) = (\sigma s C\eta/K)[(r/2) - (r_1^2/2r)] \qquad (18)$$

which when integrated gives

$$p = (\sigma s C\eta/K) \times [(r^2/4) - (r_1^2/2)\log_e r + \text{constant}] \qquad (19)$$

Assuming $p = 0$ at $r = r_1$, we obtain the following expression for the total pressure necessary to keep the interstices in the paper full between the radii r_1 and r_2.

$$p = (\sigma s C\eta/4K) \times [r_2^2 - r_1^2 - 2r_1^2 \log_e (r_2/r_1)] \qquad (20)$$

C. Application to Miniature Cable Specimens

All but two of the factors in equation 20 are already known:

$\sigma = 8 \times 10^{-4}$ cubic centimeters per cubic centimeter per degree centigrade
$s = 0.5$
$K = 12 \times 10^{-13}$ for paper (M)
$r_1 = {}^3/_{16}$ inch = 0.476 centimeter
$r_2 = r_1 + 0.065$ inch = 0.641 centimeter

The remaining two factors must be considered together since we wish to consider the most severe condition which occurs when their product is a maximum. This

Table II. Oil-Flow Data

Paper	Average Thickness in Mils	Number of Layers	$K \times 10^{13}$
M	6.5	1	12.6
M		2	12.4
M		4	12.7
M		8	12.5
M		8	12.7
M		8	12.5
M		16	12.3
N	5	1	0.587

Table III. Gas-Flow Data

Paper	Average Thickness in Mils	Number of Layers	p_0	p_2	p_1	$M \times 10^3$	$K \times 10^{13}$
M	6.5	8	76.15	77.28	79.06	.805	12.79
M			76.15	77.87	80.49	1.242	13.37
M			76.15	79.14	83.63	2.132	13.02
M			76.11	82.73	92.17	4.75	12.80
M			76.42	85.15	97.31	6.32	12.69
M			75.03	83.05	94.33	5.64	12.68
M			75.03	86.09	100.87	7.83	12.72
M			75.03	89.99	108.93	10.52	12.67
M			75.03	94.58	117.95	13.96	12.63
M			75.47	101.54	130.95	18.98	12.66
M			75.47	112.12	148.47	27.00	12.67
M	6.5	16	76.24	77.41	81.12	.811	12.04
M			76.27	77.93	83.18	1.167	12.03
M			76.28	79.76	90.35	2.44	11.85
M			76.28	81.61	97.23	3.74	11.70
M			76.28	84.16	106.17	5.56	11.65
M			76.28	84.15	105.99	5.56	11.74
M			76.28	88.11	118.76	8.42	11.60
M			76.26	93.43	134.57	12.26	11.41
N	5	1	74.99	78.91	87.25	2.72	.887
N			74.98	81.54	94.48	4.67	.909
N			74.99	84.54	102.26	6.80	.926
N			74.97	87.83	109.84	9.12	.942
N			74.99	91.54	118.42	11.80	.940
N			74.99	96.09	128.64	15.18	.926
N			74.99	101.34	139.47	19.04	.925

maximum product can be obtained graphically as shown in figure 9. Curve (1) gives the daily cooling curve taken by means of a thermocouple inserted in a glass tube extending into the oil space surrounding one of the specimens. Since the rate of cooling is slow we shall assume that the temperature is the same throughout the specimen. Curve (2) gives the rate of cooling, that is, the first derivative of curve (1). Curve (3) shows the viscosity change in oil (0) as the specimen cools. Curve (4) is the product of curves (2) and (3). As the specimen cools it is seen that the viscosity increases faster than the rate of temperature change decreases so that the maximum value of $(C\eta)$ occurs as the specimen approaches room temperature. Thus in equation 20 we shall use $C\eta = 11 \times 10^{-3}$. Then $p = 4.59 \times 10^8$ dynes per square centimeter = 0.0045 atmosphere (one dyne per square centimeter = 0.987×10^{-6} atmosphere).

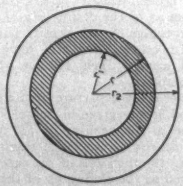

Figure 8. Cross section of a cable in which the space between radii r_1 and r_2 is occupied by paper + impregnant

In our miniature cable tests one atmosphere hydraulic pressure was maintained on the liquid surrounding the specimens so that void formation resulting from inability of the impregnant to flow in sufficient volume to keep the interstices in the paper full *was not* the primary cause of failure.

D. Application to Commercial Cable

To determine the order of magnitude of p for a commercial cable we shall assume the following data for a 69-kv solid-type cable recently installed in this country.

r_1 = 1.65 centimeters
r_2 = 3.40 centimeters
s = 0.5
$\sigma = 8 \times 10^{-4}$ cubic centimeters per cubic centimeter per degree centigrade
$K = 24 \times 10^{-13}$ (We have conducted a number of preliminary experiments to determine the average radial flow characteristics through and around standard density paper tapes of a machine insulated cable sample and found the rate of flow to be roughly double that through flat sheets.)
$C = 11 \times 10^{-4}$ (assuming the rate of temperature change in service to be the same as for our miniature specimen)

Then $p = 2.25 \times 10^8$ dynes per square centimeter = 0.222 atmosphere.

During cooling of a commercial cable, Halperin[20] shows that the hydraulic pressure in the impregnant at the sheath may drop as low as 0.16 atmosphere. Under such conditions *the hydraulic pressure would not be sufficient to keep the interstices in the paper full and void formation by this mechanism might be a significant factor in initiating ionization leading to ultimate failure.*

VI. Conclusions

1. Satisfactory equipment has been developed for absolute gas- and liquid-flow measurements through multiple layers of paper.

2. Using theoretical equations for gas and liquid flow in porous media the rate of flow of a gas-free liquid through standard-density cable paper can be calculated from air-flow data.

3. For super-calendered paper, the resistance to flow is much greater than would be indicated by the increase in average density, indicating the formation of a skin having high flow resistance on the surfaces of the paper sheet. Also the resistance to oil flow is greater than would be calculated from air-flow data and cannot be predicted from the latter, as is possible for standard-density paper. This indicates that some of the pores in the surface layers of super-calendered paper are so small that effects of absorption, adsorption, and the like on the surfaces of the cellulose fibers are no longer negligible.

4. These studies have shown that in our miniature cable samples, the resistance to flow was not great enough to cause void formation in the interstices of the paper insulation during cooling. The observed short life of specimens containing super-calendered paper or high-viscosity oil must have resulted from some other cause such as higher stress on the impregnant because of the higher dielectric constant of the paper.

5. In commercial solid-type cables using high-viscosity impregnants, on the other hand, calculations indicate that the hydraulic pressure available is not sufficient to keep the interstices of the paper full and

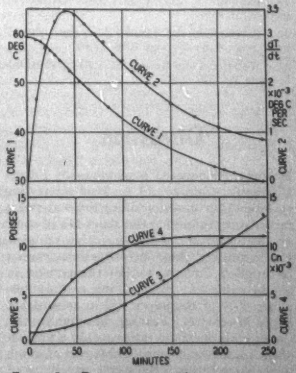

Figure 9. Determination of maximum value of $c\eta$

void formation is inevitable. This is the major argument for the use of low-viscosity impregnants and the "oil filled" principle in high-voltage cables.

Acknowledgment

The writer is happy to express appreciation to R. S. Kent, R. C. Retherford, and S. Godet for assistance in obtaining the information presented in this paper, and to H. Poritsky for checking the mathematical relations.

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Discussion

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): It is interesting to learn that gaseous ionization was not a factor responsible for the short life of some of Doctor Race's miniature cable samples. Unfortunately these investigations cannot be applied directly to the phenomena in actual cables as most of the assumptions under V-*A* of the paper will in general not apply in service. Further, in actual cables the flow through the tapes is only a portion of the total flow, a considerable part of which takes place through the spiral gaps between turns of tape. This means that the coefficient of friction of cable insulation for radial oil flow would be lower than for the author's samples. This is recognized in a parenthetical statement in part V-*D* of the paper.

Our tests on cables of the solid and oil-filled types indicate values of 4,000 to 18,000 pounds per square inch per inch thickness of insulation per cubic inch of oil per hour for oil having a viscosity of 1,000 centipoises. The value assumed by the author for 69-kv solid-type cable is 25,000 (same units), corresponding to the value of $K = 24 \times 10^{-12}$. For superdense cable insulation we find the radial coefficient of friction to be about ten times higher than for ordinary insulation, instead of 21 times as found by the author for his samples having superposed layers of paper. These lower coefficients of friction tend to reduce the probability of void formation.

In actual cables, the rate of temperature change during cooling will in general not be the same as in the laboratory models. Consideration must be given to the temperature gradient in the comparatively thick insulation of cables. The calculations on the possibility of void formation in commercial cables are over-simplified, particularly when applied to cables with thick insulation. The complete solution for pressure distribution in cable insulation was given by Miller and Wollaston in their paper "Thermal Transients and Oil Demands in Cables," AIEE TRANSACTIONS, volume 52, March 1933, page 98. By the use of this method, we have found that negative pressures will not form in oil-filled cable, except possibly under extremely severe conditions. In solid-type cables having thick insulation and high-viscosity impregnant, negative pressures may easily occur due to insufficient hydrostatic pressure. It does not follow that this cause will of itself result in voids in the insulation.

Doctor Race considers the hydrostatic pressure to be the principal factor controlling the return of compound into the insulation after expansion. It seems that the surface tension and cohesion of the compound, the capillary forces of the paper, and the adhesion between compound and paper should also have been considered. These properties are important factors in void formation.

W. A. Del Mar (Habirshaw Cable and Wire Corporation, Yonkers, N. Y.): Doctor Race has done a nice piece of work in this paper in picking out of the complicated performance of a solid-type paper cable one or two separable items which are susceptible of theoretical treatment and partial verification by experiment. One must be careful, however, as indeed Doctor Race has been, not to draw conclusions of too general a character. Thus, it might appear from Doctor Race's paper that the essential defect of a solid-type cable is the radial transfer of oil from the interior to the exterior of the insulation, leaving voids in volume equivalent to the oil forced out of the insulation.

I do not believe that this is the whole story but that to a greater extent it is the entire insulation, paper and oil, that are expanded in volume during heating, leaving a larger volume of insulation to be filled by the same amount of oil.

Impregnated paper, unlike unimpregnated paper, will take a permanent set with practically any tensile stress. It will not retain all the stretch caused by a given tensile stress when that stress is withdrawn, but it will retain a considerable proportion, usually about 15 per cent, and that will account for the increased gross volume of insulation and, as this stretch is accompanied by a corresponding reduction in tape thickness, the void space will be further augmented.

Thus we see that while Doctor Race has picked one of the variables and given it an interesting theoretical treatment, there are other variables to be considered. Doctor Race, I know, appreciates this thoroughly but I have misgivings about his application of the formulas to a 69-kv cable, fearing that someone may take it too seriously as a practical tool in cable design.

R. J. Wiseman (The Okonite-Callender Cable Company, Inc., Passaic, N. J.): I am very much interested in Doctor Race's paper as it discusses the physical properties of impregnated paper insulation. We have had many technical papers dealing with the electrical characteristics, but unless we know how the oil moves through the paper, the effect of the fiber content of the paper on the oil movement, and the pressures necessary to cause the oil to flow, we do not get a complete picture of what takes place in a paper-insulated cable. Several years ago we started a similar research, but had to postpone active work due to the urgency of other researches. However, Doctor Race has gone into the subject much more accurately than we had planned.

This paper gives us a better appreciation of the relative effect of using low- and high-weight-density papers. We know in manufacture that it requires a longer time to dry and then impregnate high-density papers. This is confirmed by Doctor Race's work. In view of the much easier flow of oil through normal-density papers, the question arises as to the desirability of using a large percentage of high-density paper in a cable. Of course, this will have to be balanced against their relative electrical characteristics.

I wonder if the departure from a straight line for oil flow as given in figure 6 is partially due to the swelling of the fibers of the high-density paper which results in an increase in the thickness of the sheet under test as well as the closing up of the spaces between the fibers suggested by Doctor Race.

The attempts of Doctor Race to apply his test data to actual cables is to be commended as it puts his work on a practical basis. The difficulty of getting close agreement with actual cables is due to several factors, such as: the view expressed by Mr. Halperin regarding flow between the layers of the paper longitudinally and along the spiral gaps; the tightness of wrapping of the layers and the difference in temperature, that is, the temperature gradient between the conductor and the sheath. Doctor Race assumes the temperature is constant for any given instant of time. For very thin walls this is true, but for heavy walls it is not. The matter of the effect of tightness of wrapping could have been studied by having the flat sheets Doctor Race tested, subjected to various degrees of compression and then determine

Application of Large Phase-Shifting Transformer on an Interconnected System Loop

By W. J. LYMAN
MEMBER AIEE

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MEMBER AIEE

A GROUP of 132-kv and 66-kv transmission systems form a loop about 300 miles in circumference and connect many important generating stations and a number of load points in the western part of Pennsylvania and the eastern portion of Ohio.

When these systems are operated interconnected at all tying-in points except one 66-kv tie north of Pittsburgh, the power exchange can be readily controlled. When this tie is closed, however, a complete ring is formed with multiple paths and an uncontrollable circulating power flows around the loop. Under such conditions, controlling the division of load over the paths and the interchange between companies requires phase-shifting equipment.

The phase-shifting transformer which is described in this paper was installed at the above mentioned point in order to make it possible to provide an emergency supply of power. Under ordinary operating conditions, this tie is open and there is no transfer of power in either direction. When, however, an unusual emergency situation develops on either system, which cannot be handled by the generating capacity associated with that system, the phase-shifting transformer can be put into operation by closing the tie and emergency power can be transferred from one system to the other.

This paper describes the phase-angle problem, the system studies made to determine the type and capacity of regulating equipment needed for the tie line, including the results of interconnected system tests, and operating performance after the installation of new equipment.

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the oil flow. However, we have a better appreciation of how much pressure is needed to maintain saturation of a cable.

It is surprising that the pressure required is not very great and naturally, one may ask why do cables fail due to migration of oil and the formation of voids. In the so-called oil-filled type of cable we use a very thin oil and the pressures that we apply at joints are of such value that we can feed oil into all parts of the cable as rapidly as is necessary to maintain a positive pressure and we, therefore, do not get voids or insulation failures. It is the ideal cable. Of course, we have another solution in the high-pressure cables which use higher-viscosity oils, but always maintain saturation because the pressure will force the oil along the cable and into the insulation. However, we have many miles of solid-type cable and we will have many more miles in the years to come. We, therefore, should consider how we can improve the solid type of cable. At the present time we use a tight-fitting lead sheath on our cables which prevents easy flow of oil from the joint along the cable between the inside of the lead sheath and insulation. We do not have any follow-up of oil with moderate pressure to feed into the insulation as the cable cools. It is true that we experience stretched lead sheaths due to the expansion of the oil in localized points along the cable. We do not want this; rather we want to be able to permit easy flow of oil back and forth along the cable. Again, we use varnished cambric wrapped joints because of the shorter time to make a joint as compared to a paper wrapped joint and we seal off the strands of the conductor from the joint compound. We believe this also is wrong. We have studied both of these factors in our laboratories and have concluded that a porous type of joint which will permit oil to flow into and out of the strands of a conductor is the proper kind to use, particularly for high-voltage cables. This, with the loose lead sheath, will reduce the high pressures produced in a cable during the heating portion of the load cycle and prevent a high vacuum to occur during the cooling portion of the load cycle. We have shown by our tests that the life of a cable is increased thereby. Doctor Race has shown us that it does not take much pressure to maintain saturation in the insulation, provided we can supply the oil when needed.

H. H. Race: In general I agree with the ideas raised in the discussion of this paper. However, there are a few points on which I should like to emphasize a different interpretation.

It seems to me that the first sentence of Mr. Halperin's discussion is a misinterpretation of our data. In conclusion IV, I stated that "the resistance to flow was not great enough to cause void formation" in our miniature cable samples. However, this does not mean that *ionization* was not the cause of failure, in fact, in most cases I believe it was and have already submitted part IV of this series of papers entitled "Mechanism of Breakdown" giving the evidence.

The last sentence of paragraph 3 of Mr. Halperin's discussion also needs clarification. When a "solid type" cable cools no voids will form and the internal hydraulic pressure will remain positive so long as the lead envelope collapses or changes its shape so as to keep the total volume within the envelope equal to the volume of the solid and liquid materials within this envelope. However, lead has little true elasticity and therefore it undergoes permanent deformation easily, and follows such volume changes very imperfectly. When during cooling the sheath reaches a point beyond which it no longer follows the shrinkage of the materials within it, *voids inevitably form.* The gas pressure in these voids may be anywhere from less than one micron corresponding to the vapor pressure of the impregnant to a fairly high pressure, depending upon the temperature and how much residual moisture, air, or other gases are present. *The "solid type" cable in which no reservoirs are provided cannot be completely free from voids or gas pockets during cooling.* The electrical gradient at which ionization will start in such gas spaces depends upon a number of factors such as gas pressure, dimensions of the gas space, proximity to an electrode and condition of the intervening solid dielectric.

A properly designed gas-free liquid-impregnated cable with sufficient reservoir capacity and liquid pressure is the only type in which voids or gas pockets cannot form during cooling.

Regarding Mr. Halperin's last paragraph, the factors he mentions certainly deserve consideration. As far as I know, however, their importance has not yet been measured quantitatively. As indicated by Mr. Delmar, the object of this paper was to give quantitative mathematical and experimental study to one factor, namely, viscous flow, which seemed most important.

The last paragraph of Mr. Wiseman's discussion advocates a partial attempt to make an "oil filled" cable out of a "solid type" cable by providing a loose sheath and porous joints so as to provide easy longitudinal flow of oil. To complete the system reservoirs must also be supplied containing sufficient low viscosity oil to keep the system full and stop joints to prevent building up excess pressures at low spots in the system. Even with these modifications a solid type cable cannot be maintained free from voids at all times. Therefore, why not use a properly designed "oil filled" system in the beginning?

Characteristics of Interconnected Systems

The interconnected systems and their geographical layout are shown by figure 1. Large generating stations are located in the Pittsburgh area at Brunots Island, Reed. Colfax, and Springdale; in the Youngstown area at Toronto, New Castle, Lowellville, and Warren; and in the Canton-Akron area at Windsor, Akron, and Cleveland. The 66-kv tie line between Valley and Ellwood is normally operated open at Valley, and the closing of this tie in an emergency is the subject of this study.

A 30,000-kva quadrature regulator or phase shifter having a range of 5.7 degrees plus or minus is located at Salt Spring substation, Youngstown, in the 132-kv Warren circuit. At Colfax there is a 36,000-kva voltage regulator in the 132-kv tie line to Springdale. The kilowatt interchange over this tie line is controlled automatically by regulating the Colfax generator output.

The reactance of the component parts of the loop system is of considerable importance in this phase-angle study. A convenient graphical method was developed for illustrating the magnitude of the reactance and the interrelation of the various sections. This is shown on figure 2 with the relative electrical distances between the stations drawn to scale in terms of the reactance of the lines, transformers, bus reactors, etc. The lengths of the solid lines represent ohmic values at 132 kv. Where several paths are in parallel, the equivalent net reactance has been calculated and is indicated by the length of the dashed lines. It will be noted that the total net reactance around the loop is 465 ohms at 132 kv.

Phase Angle and Load Transfer

The flow of power current through a reactance results in a phase-angle difference between the voltages at both ends, as shown on figure 3*A*. The *IX* drop is nearly in quadrature with the line voltage. Conversely, the insertion of a quadrature voltage in a reactive circuit will cause the flow of power current. Reactive current creates an *IX* drop in phase with the line voltage (figure 3 *B*) and so produces no angular difference. Thus, quadrature voltage controls kilowatt power flow and in-phase voltage controls reactive flow (modified slightly by line resistances).

Due to the manner in which the loads and generating capacities are distributed around the loop shown in figure 2, the voltage drops in the various circuits do not cancel out, and there is usually a relatively large phase-angle difference between the voltages at the open point. If the 66-kv tie at Valley substation is closed, as much as 12,000 kw will circulate around the entire ring, passing through all the interconnection points. This uncontrollable circulating power would naturally upset normal interchange even for those companies not directly interested. It would also increase the load on several important lines and transformers, possibly necessitating increased capacity at certain points.

Hence, if the Duquesne Light Company and the Pennsylvania Power Company desire to interchange power, some of it will pass through the direct 66-kv tie and some around the opposite direction through the other systems, with no means of controlling the division over the various circuits. A phase-shifting transformer connected in the 66-kv tie at Valley would introduce a controlled

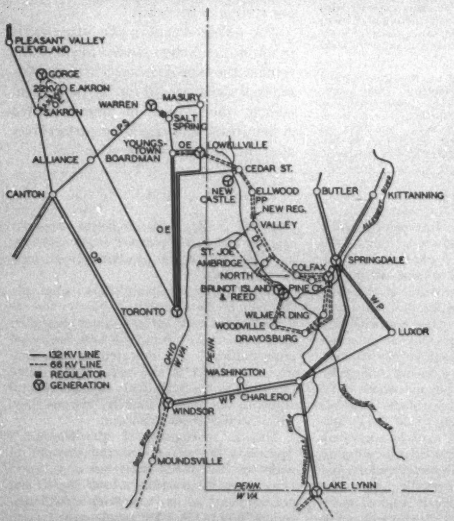


Figure 1. Pennsylvania–Ohio interconnected systems

DL—Duquesne Light Company
OE—Ohio Edison Company
OP—Ohio Power Company
OPS—Ohio Public Service Company
PP—Pennsylvania Power Company
WP—West Penn Power Company

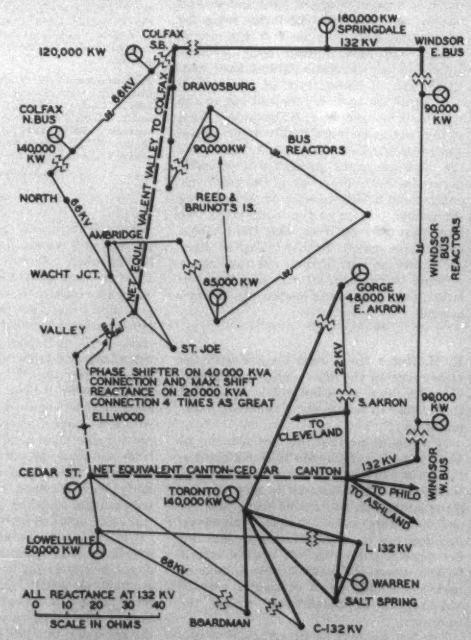


Figure 2. Equivalent reactance interconnected systems

Table I. Check of Phase Angles Around the Loop

October 1936 Tests

Circuit	Ohms per Circuit at 132 Kv	Phase Shift (Deg. per Megawatt)	Test No. 2—Normal 10:40 A.M. Megawatts	Test No. 2—Normal 10:40 A.M. Degrees	Test No. 2—Normal 10:45 A.M. Megawatts	Test No. 2—Normal 10:45 A.M. Degrees	Test No. 4—Load Shift 3:50 P.M. Megawatts	Test No. 4—Load Shift 3:50 P.M. Degrees	Test No. 4—Load Shift 4:00 P.M. Megawatts	Test No. 4—Load Shift 4:00 P.M. Degrees	Test 8a 3:15 P.M. Megawatts	Test 8a 3:15 P.M. Degrees
Valley-Wacht Junction	33.9	0.111	12.0	1.33	8.5	0.94	8.5	0.94	8.5	0.94	9.0	1.00
Wacht Junction-North	48	0.157	25.4	3.99	22.2	3.49	15.8	2.48	18.1	2.85	23.1	3.63
North-Colfax	39.8	0.130	21.4	2.78	19.9	2.59	16.7	2.17	18.2	2.36	20.2	2.63
Colfax number 1 transformer	17	0.056	43.0	2.41	41.0	2.30	36.5	2.05	30.5	1.71	46.0	2.58
Colfax number 1 reactor	39.2	0.128	16.5	2.11	12.5	1.60	9.5	1.22	3.0	0.39	17.0	2.18
Colfax number 2 reactor	39.2	0.128	5.8	0.74	0.5	0.06	−4.5	−0.58	−9.5	−1.22	9.0	1.15
Colfax number 2 transformer	17	0.056	−31	−1.74	−30.5	−1.71	−22.0	−1.23	−22.0	−1.23	−30.0	−1.68
Springdale regulator and line	50.7	0.166	−3.8	−0.63	−13.4	−2.22	0	0	0	0	3.8	0.63
Springdale-Charleroi	76.5	0.087	−8.0	−0.70	−12.0	−1.04	−10	−0.87	−9.8	−0.85	−17.0	−1.48
Charleroi-Windsor	35.4	0.116	21.5	2.50	19	2.20	16	1.86	20.0	2.32	24.5	2.85
Number 4 transformer at Windsor	53.2	0.174	22.6	3.94	20	3.48	16	2.79	20.0	3.48	24.5	4.26
Number 4 reactor at Windsor	87	0.285			−5.5	−1.57						
Reactors number 2-4	0.174	0.571			−5.5	−3.15						
Number 1 transformer at Windsor	29.2	0.096	−11.0	−1.06	−15.5	−1.49	−5.5	−0.53	−3.5	−0.34	−1.0	−0.10
Windsor-Canton number 2	46	0.151	−11	−1.66	−15.5	−2.34	−5.5	−0.83	−3.5	−0.53	−1.0	−0.15
Canton-Akron	21.5	0.071	−33.5	−2.38	−36.0	−2.55	−36.5	−2.60	−21.3	−1.51	−22.5	−0.160
South Akron transformer	26	0.085	−27.5	−2.33	−31	−2.63	−29.0	−2.46	−13.8	−1.17	−28.7	−2.44
East number 2 line	0.154	0.505	−6.0	−3.03	−4.6	−2.32	−4.0	−2.02	−7.0	−3.54	−4.5	−2.27
Akron number 1 line and transformer	79	0.259	42.0	10.90	40.0	10.37	38.0	9.87	46.5	12.07	53.7	13.94
Z-71 line and transformer	124	0.406	−6.7	−2.71	−8.9	−3.61	−5.9	−2.40	−6.5	−2.64	−6.2	−2.51
Y-53 line	34.2	0.112	−1.9	−0.21	−5.7	−0.64	−2.1	−0.24	−1.6	−0.18	−2.1	−0.24
Ellwood-Valley number 2	36.5	0.120	0		−9.6	−1.15	0		0		0	
Valley regulator	26.0	0.085	0		−9.6	−0.82	0		0		0	
Total angle—calculated				14.2		−0.21		9.62		12.9		22.4
Total angle—measured at Valley				14.0		0		7.0		13.5		28.0

quadrature voltage to compensate for the inherent angular difference and would permit satisfactory closed-ring operation when desired.

Field Tests—1928

The character of the problem of operating the 66-kv Valley interconnection closed simultaneously with the Colfax-Springdale interconnection was recognized many years ago, and the earliest effort to analyze the problem was a specially conducted series of tests in 1928. These tests consisted primarily of taking simultaneous readings on transformers and lines around the entire 300-mile loop, as it was at that time, and reading the actual phase difference between the voltages appearing across the open switch at Valley substation. These tests were described in an AIEE paper.[1]

Field Tests—1936

In 1936, it was decided to increase the interconnection capacity, largely as a result of the March 1936 flood. One of the increases proposed was a large capacity, 66-kv phase shifter in the Valley-Ellwood City tie, in order to permit parallel operation. In order to obtain accurate and up-to-date information from which to determine the required range of voltage and phase angle for the proposed regulator, another series of tests was run in the fall of 1936, similar to those performed in 1928.

These tests were conducted during the heavy load period, and arrangements were made to measure the voltages, the kilowatt and the kilovolt-ampere loads on the circuits around the loop, with the 66-kv tie at Valley open and closed, and with different divisions of load between the power generating stations. The test procedure was to take readings regularly every five minutes and to open and close the tie switch at a scheduled time between readings. In this way, data were secured with the Valley tie open and then again, five minutes later, with the tie closed, and vice versa.

Graphic records and indicating meter readings were obtained at the various points. At Valley substation, graphic records were secured of the kilowatt interchange, reactive kilovolt-ampere interchange, and the phase angle. The phase-angle record was secured on a wattmeter which had its potential coil energized from the Pennsylvania Power Company voltage through a metering transformer which shifted the voltage 90 degrees. The current coil was supplied by a constant current from the Duquesne Light Company system through a resistance load box. For diagram of connections, see reference 1. With this connection, the zero center wattmeter would read zero when the Duquesne Light Company and the Pennsylvania Power Company voltages were in phase. The readings were calibrated by use of a recording voltmeter and ammeter.

During the week following the tests, graphic charts were obtained of the voltages and phase angles. Figure 4*A* shows the phase angle variations and figure 4*B* illustrates the characteristic periodic oscillation of about five degrees occurring about 18 times per minute. This is probably the result of synchronizing power swings following the natural period of the combined system.

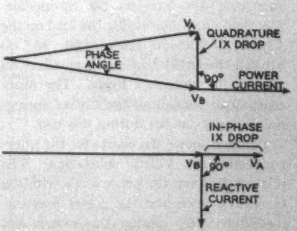


Figure 3. Relation between phase shift and power flow

1. For all numbered references, see list at end of paper.

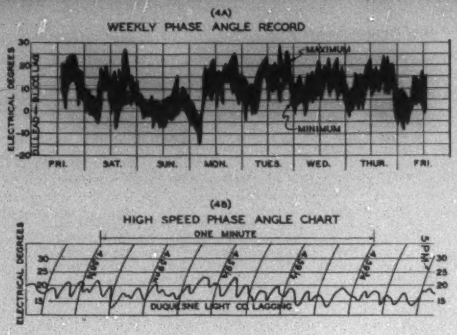


Figure 4. Phase-angle record

Summary of Test Results

One of the principal objectives of the test was to establish definitely the practicability of calculating phase angles for any given set of load conditions. The load readings were, therefore, used to calculate the phase angle and compare with the actual measured angle, and the results are shown on table I. The correspondence is very close, considering that the readings are taken from meters which are continuously fluctuating over a wide range.

Some typical power-flow and phase-angle test readings, as assembled and coordinated with the results, are shown on figures 5 and 6. It is interesting to study figure 5 and note that when the Valley tie is closed, the amount of circulating power passing through it actually appears at every point throughout the 300-mile loop. It may be seen passing through the Springdale interconnection, increasing the load on the Springdale-Charleroi lines, decreasing the load on the Charleroi-Windsor lines, and so on around the entire loop, with no effect on any of the generator loads. The automatic load control on the Colfax-Springdale tie was cut out during this test.

Figure 6 shows the charts for the interconnection at Valley substation. The relation between the phase angle with the tie switch open and the power flow immediately after closing the switch can readily be seen. During these tests the reactive kilovolt-amperes flowed in a direction opposite the power. This was due to the fact that the ratio of the original tie line autotransformer was not changed to transfer reactive power. Referring to figure 3*A*, the resistance in the system causes the current to lag behind the quadrature voltage by an angle less than 90 degrees. The circulating current, therefore, leads the line voltage.

On the 11:14 a.m. test (figure 6), 11,500 kw flowed through the Valley-Ellwood tie, and an equal amount was transferred from Colfax to Springdale. The automatic tie-line load control at Colfax was then cut in and set for zero interchange. By the time Colfax had backed off enough load to bring the Springdale tie down to zero, the Valley tie load had built up, as shown, to 22,000 kw. Efforts to control the phase angle by shifting as much as 20,000 kw between various plants did not result in changes of more than five degrees.

The normal open-circuit phase-angle difference between Valley and the Ellwood City lines during the load period 8 a.m. to 8 p.m. on week days varied between zero and plus 22 degrees (Ellwood "fast").

There is a rather definite relation between the phase angle across the open switch and the power which flows immediately on closing the switch. This ratio, as determined by test, runs from about 800 kw per degree at small angles down to 500 kw per degree for very large angles. This value may be checked analytically by taking the entire reactance around the loop, together with the voltage difference corresponding to a one degree phase angle. The result is as follows:

Reactance around loop = 465 ohms (at 132 kv)

Approximate impedance around loop = 472 ohms

Voltage corresponding to one degree =

$$V \sin 1° = \frac{0.0175 \times 132{,}000}{\sqrt{3}} = 1{,}333$$

$$I = \frac{1333}{472} = 2.82 \text{ amperes}$$

$$Kw = \sqrt{3}\,EI\,(PF) = \sqrt{3}\,(132{,}000)\,(2.82) \times \frac{465}{472} = 635 \text{ kw per degree}$$

These tests demonstrated that a phase shifter is necessary in order to use the Valley-Ellwood and the Colfax-Springdale ties simultaneously without splitting the Duquesne Light Company system into separate parts. The Valley location gives the most economical installation.

Load and Phase Angle Requirements

The range of phase-angle control required to attain the desired results is made up of two component parts: (*a*) the natural phase angle which may exist at any time due to the load and generating conditions and the resulting net power flow in each individual section of the entire loop, and (*b*) the quadrature voltage necessary to send the desired amount of power through the tie line in the proper direction. With a phase shifter capable of meeting these requirements, it would be possible to interchange power in the desired amount between the two adjacent systems without affecting in any way the generation, transmission line, or tie-line loads on the other systems involved in the loop.

The amount of phase shift needed to neutralize the natural angle involved a study of the characteristic load variations on the transmission lines and the effect of new generating capacity to be added in the future.

The limits set up for power interchange during an emergency were 40,000 kva from the Pennsylvania Power Company to the Duquesne Light Company, or 20,000 kva from the Duquesne Light Company to the Pennsylvania Power Company. These amounts are consistent with the requirements of each system and its ability to furnish power at that location.

Natural Phase Angle Between Systems

Obviously, it is not sufficient to know only what the normal phase angle will be in order to determine the phase shifter required. This phase difference varies over a wide range, depending on variations in the loads on the lines and transformers occasioned by changes in load, generation schedules, and emergency conditions. In general, the line loadings around the 300-mile ring tend to cancel out, and if the location of the loads and generation were entirely symmetrical, there would be no phase difference at Valley.

It is known, however, that load on lines feeding in one direction might possibly increase at the same time those feeding in the opposite direction would decrease. This would greatly increase (or decrease)

the phase difference at Valley. It is entirely possible to secure extremely large angles in this manner, but if this occurrence is to be infrequent, it would not be economical to provide for it. Consequently, the proper solution cannot be reached by providing for the worst possible condition.

In order to reduce this problem to more definite and tangible terms, the probability theory was applied to the basic information to determine the likelihood that the angle will exceed any given amount in either direction. This analysis has been limited to the period from 8 a.m. to 8 p.m. on week days. The phase difference during light loads is much less.

The first step was to study the actual angular difference which existed and which could be measured at Valley substation. The combined result of many readings taken over several months is shown on figure 7. The angle varied from 0 to 22 degrees, with 11 degrees to 13 degrees occurring most frequently.

Probable Variation

Most variable conditions which center about an average figure, but deviate from this average with a frequency which decreases as the deviation increases, can usually be represented by the standard "bell" shaped distribution or probability curve. The experience curve on figure 7 was plotted so as to show the percentage of the total number of readings of any particular angle. This curve has the characteristic "bell" shape and can be represented very closely, as shown by the series of crosses, with a standard curve.

The hourly loads of each individual line or transformer, when plotted as a frequency distribution curve, will follow this general "bell" shape, having a certain average value, and varying above and below this average or mean by an amount depending on how widely the load fluctuates (8 a.m. to 8 p.m. load period only being considered here). If the curve for each line and transformer were available, they could be converted into phase angles (by using the load and impedance) and combined to obtain a probability curve for the phase angle at Valley. The measure of the magnitude of the variation of a probability curve is called the standard deviation which is the root-mean-square of the deviations of all the individual points from the mean. It can be shown from the characteristics of the standard probability curve that the chances are two to one (2/3) that the load will not deviate from the mean by more than the standard deviation. Furthermore, the chance that the load will exceed any given amount may be determined from the probability curve or standard tables.

A study was made, therefore, of actual line load variations and representative probability curves obtained. The average value of the standard deviation for these curves was found to be 15 per cent of the average load during the 8 a.m. to 8 p.m. load period. This means that for only one-third of the time is the load more than 115 per cent or less than 85 per cent of the average.

If there are several lines and transformers in a loop, each carrying a load independent of the others, and varying approximately according to the standard probability curve, the net phase shift of the whole group will also be a probability or "bell" shaped curve. The "S.D." (standard deviation or spread) of this total curve will be the root-mean-square of the "S.D.'s" of the individual circuits.

Load changes due to a general increase in system loads will not greatly affect the angle since they will tend to balance out, and it is only the independent variations due to local conditions which affect the problem. It was found by examination of simultaneous loads around the loop that 30 per cent of the variation is common to all circuits, so that the effective standard deviation is only (100 per cent–30 per cent) × 15 per cent, or about

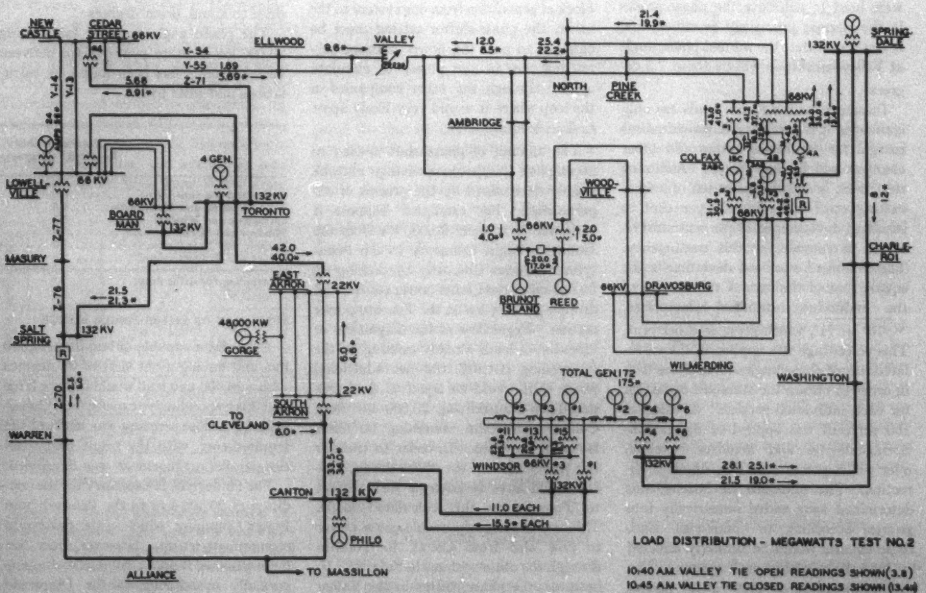


Figure 5. Load distribution—megawatts

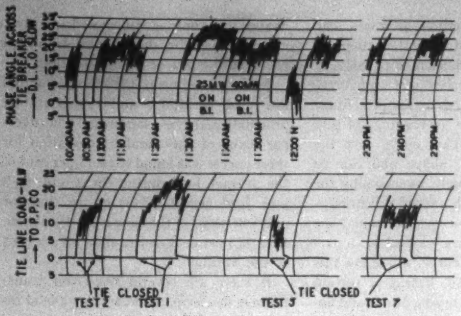


Figure 6. Relation between phase angle with tie open and power flow with tie closed

11 per cent, for individual circuits. Using this figure of 11 per cent applied to all circuits around the loop gives a phase angle variation curve for Valley with a standard deviation of 3.7 degrees. This compares favorably with the 3.8-degree standard deviation of the average curve on figure 7, taken from actual readings.

Future Phase Angle Conditions

The next step was to secure estimates by the various companies included in the transmission ring of the expected normal loads on their lines and transformers during heavy load periods after the installation of the scheduled generators at Reed, Springdale, Windsor (two 60,000-kw units), and New Castle. These loads were used to calculate the phase angles in the manner previously described, and it was found that the normal phase angle at Valley substation will be about 7.5 degrees.

Inasmuch as the future loads are only estimates, it is necessary to provide some margin for estimating errors and other changes which may occur. Assuming that there is one chance in ten of a forecasting error exceeding 25 per cent, a standard deviation of 15 per cent must be added to provide for this contingency. The combined standard deviation is the square root of the sum of the squares of the individual standard deviations, $\sqrt{15^2 + 11^2}$, which gives 18.6 per cent. This percentage was applied to the calculated future phase angles around the loop in order to obtain the standard deviation for each individual section. A value of 100 per cent was applied to the Colfax-Springdale tie and Windsor reactors, over which power may flow in either direction. The standard deviations thus determined were added numerically into groups, according to companies, since these circuits would be similarly affected by load shifts within each system. The root-mean-square of these latter figures gave the standard deviation for the angle at Valley as 6.4 degrees.

The resulting curve at the bottom of figure 7 shows, for example, that the angle will exceed 20 degrees about two per cent of the time, and will be less than −5 degrees about three per cent of the time. This curve gives a definite basis for applying a regulator with a fixed minimum range to compensate for an angle which has no fixed limits and which may vary over a very wide range.

Power Transfer

After setting the phase shifter to compensate for the natural angular difference, the tie line can be closed and no power will flow. If, then, it is desired to shift a block of generation from one system to the other, the phase-shifter setting must be changed to pass the power without permitting any of the power to circulate around through the other companies in the loop where it would very likely upset tie-line loadings.

The amount of phase shift needed to accomplish this power exchange may be readily determined by the process of superposition. For example: Suppose it is desired to transfer 20,000 kw from the Duquesne Light Company to the Pennsylvania Power Company by picking up 20,000 kw at the Colfax power station and dropping 20,000 kw at the Toronto power station. Regardless of the magnitude or direction of loads already existing on the intervening circuits, the net additional phase shift would be equal to that produced by transmitting 20,000 kw from Colfax to Toronto, assuming no other loads on the lines. In order to transfer this power without the phase shifter, Colfax would have to advance with respect to Toronto by this calculated angle. This, quite obviously, would cause power to flow also from Colfax to Toronto through the other systems in the ring. If, however, the phase shifter in the Valley tie is advanced by an amount equal to the calculated angle, Colfax and Toronto will not change their relative angular positions, and the only power flow will be the 20,000 kw from the Duquesne Light Company to the Pennsylvania Power Company through the Valley-Ellwood tie.

The phase angle produced by a given kilowatt load is not greatly affected by the power factor of the load on a system composed of transformers, reactors, and large capacity overhead lines, with consequent low ratios of resistance to reactance. It can be calculated approximately by the formula:

$$\text{Angle (degrees)} = \frac{(KW)\,(\text{Reactance})\,0.057}{(KV)^2}$$

$$\text{Note: } 0.057 = \frac{1}{1000 \sin 1^\circ}$$

The phase shift corresponding to the requirement of transferring 20,000 kw to the Pennsylvania Power Company, as described above, was found by calculation to be eight degrees (exclusive of *IZ* drop in phase shifter). Since the natural angle may be 20 degrees (Pennsylvania Power Company leading Duquesne Light Company), a total net range of 28 degrees would be necessary in order to be able to furnish 20,000 kw under all reasonable conditions. If the power factor of the interchange were 90 per cent lag, the above value of eight degrees would reduce to about seven degrees.

The phase angle required for shifting 20,000 kw at unity power factor between various points has been found by calculations and tests to be:

	Net Phase Shift Required* (Degrees)
Colfax and Toronto	8.0
Brunots Island and New Castle	6.5
Springdale and Windsor	3.5
Windsor and Philo	2.5
Toronto and New Castle	3.0
Colfax and Brunots Island	1.5

* Excluding regulator drop.

Selection of Phase-Angle Range

A regulator capable of handling 40,000 kva and having a net shift of 28 degrees with a 20,000-kva load would be very large and correspondingly expensive. Consequently, a close scrutiny was made of the requirements, with the result that a series-parallel arrangement was developed.

The 28 degrees is necessary for the condition of 20,000 kva to the Pennsylvania Power Company, which is the maximum requirement set up. However, since the Pennsylvania Power Company voltage is normally in advance of the Duquesne

Light Company voltage, a smaller phase shift is adequate to transfer power to the Duquesne Light Company. By the simple expedient of dividing into two parts the windings which carry the line current and providing a series-parallel switch, it was possible to reduce the rating of the regulator to 20,000 kva and 28 degrees net (33 degrees no load) on the series connection. By changing to the parallel connection, the carrying capacity becomes 40,000 kva, and the available phase shift of 15 degrees net (18 degrees no load) is adequate to transfer full load to the Duquesne Light Company under all reasonable conditions.

The phase shift requirement for either company to take power through the Valley tie is materially reduced (about five degrees) if the company is at the same time taking power from other interconnected systems. This would be the normal condition during an emergency. Should conditions arise when the phase shift required is greater than the regulator capacity, the result is not serious. For a five degree shortage, the Valley tie will carry 3,500 kw less than desired and the other tie 3,500 kw more than the desired amount.

Load Increments

With 20,000 kw at unity power factor transferred as described above, the total phase shift would be 8 degrees through the systems, plus 5 degrees in the regulator itself, or 13 degrees. The load shift per degree is, therefore, computed to be about 1,500 kw when shifting between Colfax and Toronto. As shown by previous tests, and verified by calculation, an angle of one degree will send only 600–800 kw around the entire 300-mile loop. In this connection, the automatic load controller on the West Penn Power Company tie line at Colfax must be taken into account. A sudden insertion of one degree, such as by changing taps on the phase shifter, would circulate about 800 kw around the entire loop. This power, which would also flow through the West Penn tie at Colfax, would operate the tie line load controller, which would change the Colfax generation to return the tie line load to its original value. This would further increase the load change through the phase shifter after a brief interval to about 1,500 kw, corresponding to a transfer between the adjacent systems only. If the regulator steps were two degree each, the kilowatt change per step would be 3,000, which is not considered excessive, and is less than the normal power oscillations which occur continuously.

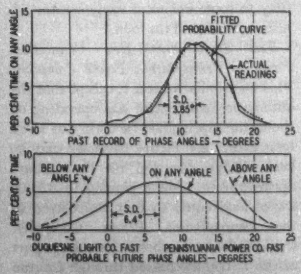
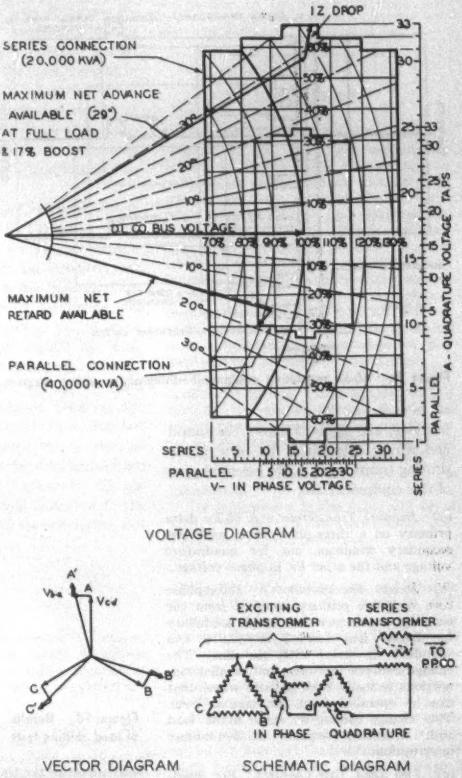


Figure 7. Natural phase-angle variation between Duquesne Light Company and Pennsylvania Power Company at Valley (no load on tie) Monday to Friday inclusive—8:00 a.m. to 8:00 p.m.

Figure 8. Regulator diagrams



Voltage Regulating Requirements

It is also necessary to provide an adequate range of voltage control in the regulating equipment. The normal voltage on the Duquesne bus at Valley is 63–65 kv. With a load transfer to the Pennsylvania Power Company of 20,000 kw at 0.8 power factor, the Duquesne bus would have a voltage regulation of 4.2 per cent and the regulator would, therefore, have to raise the voltage from approximately 61 kv to the required value of 71 kv, or 16 per cent net boost.

The normal voltage on the Pennsylvania Power bus at Valley is 65–68 kv. When supplying 40,000 kva at 0.9 power factor to the Duquesne Light Company, the voltage would be 60.5 kv. The desired voltage at Valley under this condition is 65.5, or a net boost of eight per cent (buck toward Pennsylvania Power Company).

Description of New Regulator

The single-line diagram on figure 8 shows the schematic arrangement of con-

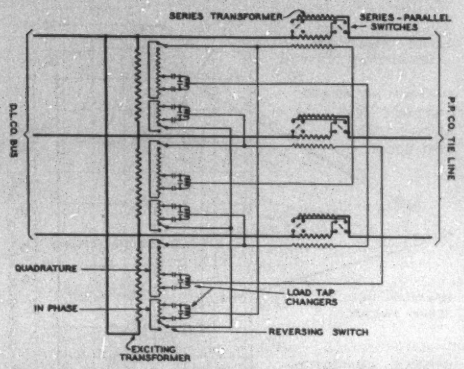


Figure 9. 66-kv regulating equipment—three-phase wiring diagram

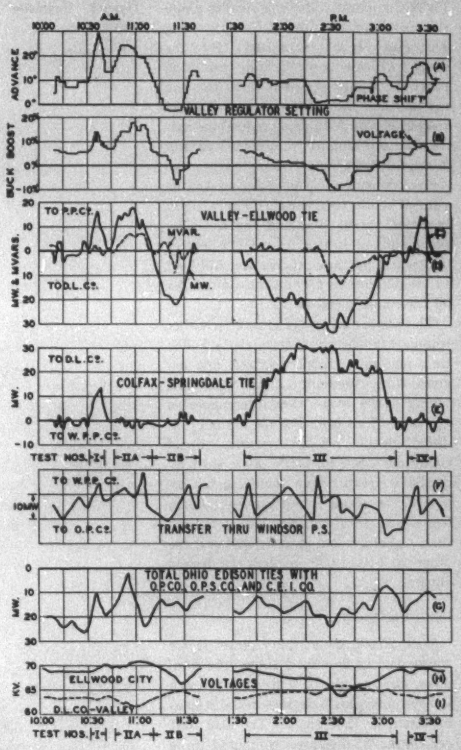


Figure 10. Results of load shifting tests

nections, and figure 9 shows the simplified wiring diagram of the new phase-shifting transformer. The essential parts of this equipment are:

(*a*) *Exciting Transformer.* A 65-kv delta primary on a three-phase core, with two secondary windings, one for quadrature voltage and the other for in-phase voltage.

(*b*) *Series Transformer.* A three-phase core with one primary supplied from the exciting transformer and double secondary for 20,000 kva (series) or 40,000 kva (parallel) in series with the line. The change between the series and parallel connections is made with a hand wheel that can be operated from the ground level. This change cannot be made under load and, therefore, requires a five-minute interruption.

(*c*) *Two Load Tap Changers.* For quadrature and in-phase voltages, each with 33 steps, 16 on either side of neutral.

(*d*) *Two Preventive Autotransformers* for tap changing under load.

(*e*) *Fans* for increased rating. Rating 15,000/30,000 kva self-cooled and 20,000/40,000 with fans.

The voltage diagram on figure 8 shows the range of phase shift and voltage control available. In order to secure the net shift of 28 degrees on the 20,000-kva connection, a quadrature voltage of 67.5 per cent was needed. This would give 33.75 per cent quadrature voltage on the parallel connection. In order to utilize this and obtain an eight per cent boost when feeding toward the Duquesne Light Company (eight per cent buck toward the Pennsylvania Power Company) a 16 per cent buck was required as shown on the diagram. This determined the in-phase voltage required, although the resulting 32 per cent on the series connection is not all needed.

The quadrature tap changer can be made to operate automatically from a watt-meter in the tie line, in order to hold the load within any desired range.

Results of Tests on Completed Installation

Arrangements were made to perform some load-shifting tests as soon as the regulator was available for service, in order to verify its ability to perform the functions for which it was designed. The load charts reproduced on figure 10 show the power interchange over the tie lines between the various systems making up the loop. The tests may be described briefly as follows:

Test I—20,000-Kva Connection, Power to Pennsylvania Power Company. With the automatic load control on the Colfax-Springdale tie inoperative, 15,000 kw were sent to the Pennsylvania Power Company by the phase-shifter control. The 15,000 kw flowed around the entire loop with practically no effect on generator output. Under similar conditions, during a previous test (before the phase shifter was installed) it had been impossible even by adjusting generator output and switching, to transfer any power directly from Valley to Ellwood substations.

The power flow per degree of phase shift was found to be 790 kw per degree. This is higher than the theoretical average value of 635 kw per degree due possibly to some unlooked for generator adjustments around the loop.

Test II-A—20,000-Kva Connection, Power to Pennsylvania Power Company. This was similar to test I, except that the automatic load control was operating on the Colfax-Springdale tie as it was in all tests except I. Figure 10 shows that no load change occurred on the Colfax-Springdale tie, Colfax picking up 15,000 kw of load equal to that transferred to the Pennsylvania Power Company. Curve *G*, however, shows that a large part of the 15,000 kw passed through Canton and South Akron and to the neighboring companies on the west.

The load shift at Valley proved to be 1,220 kw per degree, instead of 1,500 kw per degree, as had been calculated for a

transfer from Colfax to Toronto, obviously because the load picked up at Colfax was dropped by power stations beyond the Ohio Edison Company system.

The 15,000 kw were transferred on regulator quadrature voltage tap *A*-28. Two more steps to tap *A*-30 would have increased the load to about 20,000 kw. The three remaining steps would have transferred the 20,000 kw even if the Pennsylvania bus voltage had been 18 degrees ahead of the Duquesne bus voltage (tie open) instead of 12 degrees as it was during this test. Furthermore, if all the load decrease had been made at the Ohio Edison Company plants, there is no doubt that the 20,000 kw transfer could have been made in the face of a natural phase difference of 20 degrees, thus demonstrating that the phase-angle range provided is neither too small nor unnecessarily large to accomplish the established requirements.

Test II-B—20,000-Kva Connection, Power to Duquesne Light Company. About 20,000 kw were sent from the Pennsylvania Power Company to the Duquesne Light Company. In this case Colfax dropped 20,000 kw and most of it was picked up on the Ohio Edison Company plants, only about 5,000 kw coming through its ties to the west. The power shift in this case proved to be 1,530 kw per degree, which corresponds very closely with the predicted figure of 1,500 kw per degree for transfer between Colfax and Toronto. The method of analyzing this part of the problem is thus fully substantiated.

On this test, reactive power was transferred in order to adjust the power factor to the desired value. Each two per cent in-phase step transferred about 1,700 kilovars. Each 4.2 per cent quadrature step transfers about 3,000 kw between Duquesne Light Company and Ohio Edison Company. The greater effectiveness of the in-phase voltage is due to the fact that the only impedance to be overcome is between points where the voltage (magnitude) is held constant, which points are closer together than the generating stations between which power is being transferred. Synchronous motors and condensers also tend to maintain the voltage magnitude, but not the phase relation.

Test III—40,000-Kva Connection, Power to Duquesne Light Company. This test was run to demonstrate the ease with which desired amounts of power may be obtained by the Duquesne Light Company from both the West Penn Company and the Pennsylvania Power Company. A total of 64,000 kw was obtained, divided nearly equally between the two interconnections. With system conditions as they were at the time, very little phase shift was needed, but during emergencies such as would require this large amount of power, the phase-angle conditions would vary over a considerable range and most of the 15 degrees available would be needed.

Test IV—40,000-Kva Connection, Power to Pennsylvania Power Company. This test was performed to see how much power could be sent to the Pennsylvania Power Company with the limited range available on the parallel connection and the natural angle existing at the time (12 degrees). About 14,000 kw were transferred, using the full range of 18 degrees (no load). This average of 2,300 kw per degree is greater than on the series connection because the impedance of the regulator is only one-quarter as great. This reduces the total impedance between Colfax and Toronto by 33 per cent, which corresponds closely with the relation between 1,535 kw per degree and 2,300 kw per degree.

Conclusions

1. A regulating transformer to control phase angle as well as voltage magnitude is necessary in order to utilize successfully the tie line between Valley substation and Ellwood City.

2. The methods outlined herein for analyzing the characteristics of the interconnected system are entirely practical and accurate for determining the size and range of the in-phase and quadrature voltage control required.

3. The phase-shifting and voltage-regulating equipment, as installed, performed satisfactorily and gave positive and independent control of the kilowatt and reactive flow through the tie line under the desired conditions.

4. The use of a series parallel (20,000–40,000 kva) arrangement permitted a more economical solution of this problem where special load carrying and phase-shifting requirements had to be met.

5. The method outlined herein for expressing the future phase-angle variations by use of the probability theory is believed to be applicable to a variety of other problems of a similar nature.

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2. Interconnected Power Systems, Philip Sporn. Electrical Engineering, January 1938, page 16.

3. Economic Statistics (a book), Crum and Patton. A. W. Shaw Company, Chicago and New York City, page 199.

4. Probability and Its Engineering Uses (a book), Fry. D. Van Nostrand & Company, Inc., New York City.

Discussion

Robert Treat (General Electric Company, Schenectady, N. Y.): The considerable number of studies made, and of inquiries received for quotations on phase-shifting transformers over a period of years indicates that this subject has intrigued the imaginations of many utility engineers. The small percentage of such inquiries which have resulted in orders, however, indicates that the cost of solving the problem by this means has generally been considered disproportionate to the expected benefits. It would appear that most of the problems have been solved in a less expensive, perhaps also in a less satisfactory, manner.

This paper is of interest in that it describes one case in which a really competent and penetrating analysis showed the installation of a phase-shifting transformer to be economically justified. Operating experience appears to have confirmed the wisdom of the decision to proceed with the installation.

The information in this paper will be of great value to other engineers who are confronted with similar problems.

Philip Sporn (American Gas and Electric Service Corporation, New York, N. Y.): The type of transmission loop, described by Messrs. Lyman and North in this paper, is distinctly a product of the interconnection idea, as carried out by the various companies involved in this loop, including particularly the company with which I am associated. This problem of loop operation and inability to maintain complete control of power flow over individual portions of such loops is one that we are confronted with continually.

The authors have described a very thorough method of analysis of their particular problem, from the standpoint of both computations and field observations. The graphical representation of the actual and equivalent loop reactances as shown in figure 2 of the authors' paper is novel and helpful, and the application of probability theory to the selection of the range of control which can be economically justified, is also a sensible and practical means of approach. In fact, starting out on the premise that fairly complete control of power flow is necessary on an interconnection of this type in order to obtain the advantages of the interconnection, the authors have attacked and solved the problem in a sound and clever manner.

However, in the light of the experience we have gained in operating interconnected systems, I should like to raise a question as to the premise on which this entire study was based. At the outset it is stated that the interconnection is to be used only in case of an unusual emergency situation to provide an emergency source of power. I should like to ask why, as an emergency proposition, it would not have been possible to have taken care of the emergency by simply closing the switch at Valley, regardless of the particular phase-angle situation

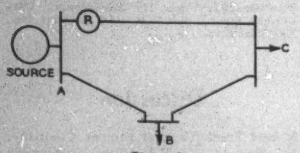

Figure 1

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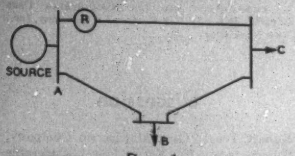

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Figure 2. Rear view of test car showing instrument cases on top shelf, test transformer with control panel, oil test cup, and tool box on second shelf, and high-voltage test cable coiled in cylindrical pan on car floor

by one slide-rule setting. Other miscellaneous equipment, such as standard condenser, oil cup, test leads, guard circuit, safety switches, etc., comprise the balance of the equipment. All major test equipment is specially designed, and

Figure 3. Field test of oil circuit breaker. The test man reads his instruments without removing them or the test transformer from the test car. The other man, standing on the ground, connects the test lead to the bushing with an insulated switch stick

carefully shielded—an important feature required for use in the field.

In actual operation, the test equipment is carried in a light delivery truck as shown in figure 1. A view of the rear of the truck, with full door opening, is shown in figure 2. The interior of the truck has been specially fitted with shelves and partitions to hold the test equipment, not only rigidly in place during transit, but without being moved when testing is in progress. Figure 2 shows the instrument case on the top shelf, the test transformer, oil cup, and tool box on the middle shelf, and the 60-foot test lead coiled in a cylindrical container on the floor. A typical field test on an oil circuit breaker is shown in progress in figure 3.

The test schedule was first set up on a yearly basis. As the test work was extended each year to other equipment not contemplated when the schedule was first arranged, equipment has been tested every 18 months to two years instead of yearly as initially planned. At the present time we have three test sets in continuous use throughout the year.

All fault conditions found are immediately brought to the attention of the person in direct charge of maintenance, and major faults are recommended for immediate correction. Minor faults are pointed out, but are usually left until regular maintenance periods, or until next periodic test, according to the apparent importance of the fault and service conditions.

Copies of all field test records giving classification of faults according to severity, and recommending servicing procedure are promptly distributed to the person in charge of operation, to the Doble Engineering Company, and to the engineering department of the American Gas and Electric Service Corporation. Although the field-test men make the initial recommendations for servicing faulty equipment, subsequent triple review of the test data and recommendations are possible by the above procedure. Be it said to the credit of the test men, rarely has any exception been taken to their initial recommendations given at the time the tests were made in the field.

From the very start of this test program it was believed that the best results would be obtained by placing the test set in the hands of a technically qualified man, specially trained in this type of work, making tests continuously, and held highly responsible for the progress made and the recommendations given. Our experience bears out this belief. Such a man often detects fault conditions in the field which can easily be overlooked by adherence to an arbitrary set of power factor, watt loss, current, or other limits. Such limits are, however, essential as a basis of evaluating faults, although supplemental tests or inspections have frequently detected faults which would not have otherwise been found.

IV. Detailed Test Methods

In applying test voltage 10 kv is used unless this is above the safe limit of the equipment being tested or unless the charging current exceeds the range of the measuring instruments. If such conditions exist, the applied voltage is reduced to 5.0, 2.5, or 1 kv as required.

Oil Circuit Breakers

The method of testing oil circuit breakers has previously[1] been described in detail. It consists essentially in testing each bushing separately, with the breaker open, and each tank separately (two bushings plus internal cross connection) with the breaker closed. It is usually unnecessary to disconnect the external leads to the bushing unless a fault condition is found. Evaluation of watts, power factor, and in some cases current (See V—"Classification of Faults" and table III) enable the classification of the insulation condition.

Transformers

Testing the insulation of transformers by the power-factor method differs somewhat from the procedure followed in oil circuit breakers, first because physical separation of bushing from the internal insulation (winding) is usually not possible without opening the transformer tank (which involves extra labor), and second because it is often desirable to test the insulation of both windings of a transformer as well as their interwinding insulation. Also, another important feature that has to be considered is the relative large magnitude of watts loss and current in winding insulation as compared with those in bushings. This can easily obscure the fault in a transformer bushing unless it is disconnected and tested separately, or other means of test and analysis are used.

With instrument transformers such special test means and analysis have been

Table I. Test Procedure on Instrument Transformers
(See Figure 4)

Test Number	Meter Reading	Connections: Test To	To Ground	To Shield
1	$W_H + W_B + H_1 + H_3$	$H_1 + H_2$	L_1 L_2	
2	$H_1 + X^1$	H_1	L_2 or L_1	H_2
3	$H_2 + X^1$	H_2	L_2 or L_1	H_1

Table II. Test Procedure on Power Transformers
(See Figure 4)

Test Number	Meter Reading	Connections: Test To	To Ground	To Shield
1	$W_H + W_B$	H_1 and H_2	L_1 and L_2	
2	W_H	H_1 and H_2		L_1 and L_2
3	$W_L + W_B$	L_1 and L_2	H_1 and H_2	
4	W_L	L_1 and L_2		H_1 and H_2

successfully used to segregate winding faults from those in bushings. The procedure we have used is as follows: Referring to figure 4*A*, which represents a typical transformer, test voltage is applied simultaneously to the high voltage terminals H_1 and H_2, one terminal only of the low-voltage winding being grounded. A second test is now made with voltage on H_1, and H_2 connected to shield, other connections remaining the same. The third test is a repeat of test number two, with connections H_1 and H_2 reversed. The first test shows the over-all insulation condition of the transformer; the second and third tests (called cross checks) give, by comparison, the condition of each bushing. These three tests are outlined in table I. Where serious faults are indicated the bushings are separated from the winding and all tested separately. The insulation of the low voltage coil to ground is not tested as practical considerations have not yet indicated this is necessary.

In testing power transformers the loss in secondary winding insulation to ground must be measured and all winding losses evaluated. This has been done by the four tests outlined in table II. By proper combination of measured values the losses in, and power factor of, all three insulation paths can be obtained. The determination of the condition of the bushing insulation is not quite as simple here as with the instrument transformer on account of the relatively higher loss in the high-capacitance transformer windings. Several methods are available and have been used for determining the condition of the bushing alone without disconnecting it from the winding.

First, a comparison of the relative power factors of high, low, and interwinding insulation which shows abnormally high loss insulation to ground usually indicates one or more faulty bushings connected to high-loss winding. Second, if the bushing is of the drawlead type, the lead can be lowered inside the transformer tank by means of an insulating rod, and the bushing tested separately. A third method (hot-collar test) described below has also been successfully applied as an individual bushing test in some cases.

Hot-Collar Bushing Test

This test, which has recently come into use, is applied to bushings only, and consists of grounding the normally "hot" terminal of the bushing and applying the 10-kv test potential successively along the bushing at recesses between porcelain corrugations, and measuring the watts loss. Contact with the porcelain is made either through tinfoil wrapped around the entire porcelain circumference, or through a circular flat spring clamp which clips between the porcelain watersheds. This clip is energized on test, hence the name hot collar.

By this test a considerable number of faulty bushings have been detected, which upon examination were found to have such faults as cracks in the porcelain, porous porcelain, water (as much as a one-half cupful) inside the bushing at the top, and distributed moisture in the interior of the bushing. The test has always shown faults detected by the power factor test, and also faults such as the above, some of which the power factor test had not picked out.

Solid Insulation

Solid insulation such as wooden switch sticks, hot line sticks, and fibrous insulation such as insulating cylinders in bushings are being tested regularly by the power-factor test set. The standard test used is 10 kv between tinfoil or other metallic wrapping placed at three-inch intervals along the stick or cylinder, and

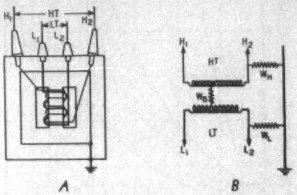

Figure 4. Insulation diagram of transformer

A—Typical transformer
B—Equivalent insulation diagram
HT—High-voltage side
LT—Low-voltage side
H_1 and H_2—High-voltage bushings and losses
L_1 and L_2—Low-voltage bushings and losses
W_H—Watts loss, high-voltage insulation to ground
W_L—Watts loss, low-voltage insulation to ground
W_B—Watts loss, insulation between high-voltage and low-voltage
X—Watts loss, $W_{B'} + W_{H'}$, where prime (′) equals the loss with one end of high-voltage grounded

insulation rating based on watts loss. While the technical justification why such a test is sound, is not at first clear, involving as it does creepage paths along the stressed surface of the insulation as well as the direct insulation path through it, it is a fact, however, that it is a practical and effective method of locating insulation defects in wood members and fibrous insulation.

Allocation of Trouble

Tests of this type are extremely helpful in definitely locating trouble, determining the cause, and applying corrective measures, once a piece of equipment such as a bushing or transformer has been found defective. The mere knowledge obtained by a test that shows equipment is faulty without allocating the trouble is only one step in maintaining electrical equipment in good operating condition. The tracing of the trouble to its source is just as important as finding a faulty piece of equipment, for the type and location of the trouble determines the nature of servicing required, even at times to the desirability of scrapping parts of or the entire equipment. This insight into insulation, the power-factor

Table III. Basic Rating for Insulation Quality From Power-Factor Field Tests
(Corrected to 20 Degrees Centigrade)

Apparatus	Type	By Per Cent Power Factor Good (G)	Deteriorated (D)	Remove (R)	Remarks
Bushings	Comp. filled	Below 4.0	4.0 to 6	Above 6	
	Oil filled	Below 3.5	3.5 to 5	Above 5	Fibrous barrier
	Oil filled	Below 4.0	4.0 to 6	Above 6	Porcelain barrier
	Condenser	Below 3.5	3.5 to 5	Above 5	1-piece porcelain
	Condenser	Below 3.5	3.5 to 6	Above 6	Multi. shed
	Semicond	Below 4.0	4.0 to 7	Above 7	Also bulk type
Transformer-winding	C. T	Below 3.5	3.5 to 6	Above 6	With bushings
	C. T	Below 3.5	3.5 to 7	Above 7	Winding only
	Power and P. T	Below 3.5	3.5 to 5	Above 5	
		By Watts Loss			
Oil circuit breakers	Most	Below 0.2	0.2 to 0.5	Above 0.5	Loss in tank
	33 Kv	Below 0.15	0.15 to 0.3	Above 0.3	Loss in tank
Herkolite cylinder	3-inch	Below 0.1	0.1 to 0.5	Above 0.5	Between bands
Wood bushings	3-inch	Below 0.1	0.1 to 0.5	Above 0.5	Between bands
	Comp. and cond	Below 0.2	0.2 to 0.5	Above 0.5	Hot-collar test

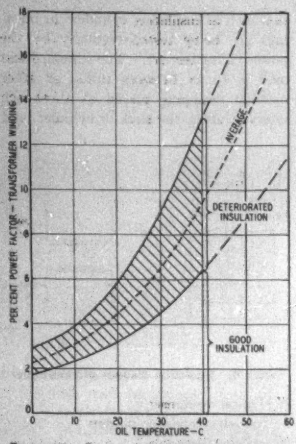

Figure 5. Power factor versus temperature correction curve for transformer winding (from field tests)

Table V. Power-Transformer-Bushing Faults Segregated as to Type, Summary of Four Years of Field Testing
(January 1934 to October 1937)

Type of Bushing*	Test	Number of Bushings Tested	Defective		Remove		Average—3 Tests	
			Number	Per Cent	Number	Per Cent	Per Cent D	Per Cent R
A	First	1,182	31	2.6	46	3.9	2.5	2.8
	Second	772	15	1.9	12	1.6		
	Third	134	7	5.2	0			
B	First	875	77	8.8	58	6.6	8.7	5.0
	Second	447	28	6.3	8	1.8		
	Third	128	22	17.2	9	7.0		
C	First	2,515	100	4.0	141	5.6	4.0	5.5
	Second	1,399	52	3.7	76	5.4		
	Third	175	10	5.7	6	3.4		
D	First	2,132	22	1.0	26	1.2	0.8	0.9
	Second	1,071	5	0.5	6	0.6		
	Third	252	0		0			
E	First	1,025	19	1.9	11	1.1	2.0	1.3
	Second	722	13	1.8	11	1.5		
	Third	145	5	3.4	3	2.1		
Total	First	7,729	249	3.2	282	3.7	3.1	3.2
	Second	4,411	113	2.6	113	2.6		
	Third	834	44	5.3	18	2.2		

* Types of bushings refer to different basic principles of bushing design.

test set, with its direct readings of current and watts has been able to do with a high degree of certainty.

V. Classification of Faults

From the time the insulation in a piece of equipment leaves the factory in good condition until the end of its useful life (usually a period of years) it undergoes deterioration to a degree dependent on many factors such as duty in service, the elements, field servicing procedure, and faulty design. In the field testing of such insulation, by the methods described above, one of the immediate objectives is to determine, if possible, when the deterioration has become serious enough to warrant attention. The fault may be just starting and not serious but can be economically cured without allowing it to develop into a service failure. Again it may be so serious that immediate attention or even prompt removal from service is necessary.

Following this line of reasoning we have set up three classes of insulation as determined from test results. These are:

1. Good (*G*). No attention required.
2. Deteriorated (*D*). Not as good as new but not requiring special servicing until the next periodic test is made to check its condition.
3. Remove (*R*). Remove from service and recondition or scrap as conditions warrant.

Table IV. Bushing Faults, Summary of 5½ Years of Field Testing
(May 1932 to October 1937)

Test	Number of Bushings Tested	Defective		Remove	
		Number	Per Cent	Number	Per Cent
A. Power-Transformer Bushings (All kv ratings)					
First	7,729	249	3.3	282	3.7
Second	4,411	113	2.5	113	2.5
Third	834	44	5.3	18	2.2
Total	12,974	406	3.1 average	413	3.2 average
B. Power-Transformer Bushings (All kv ratings, excluding 15-kv and below)					
First	4,152	198	4.8	205	4.9
Second	2,477	84	3.4	57	2.3
Third	443	35	7.9	15	3.4
Total	7,072	317	4.5 average	277	3.9 average
C. Instrument-Transformer Bushings					
First	2,581	74	2.9	97	3.8
Second	2,145	70	3.3	73	3.4
Third	724	43	5.9	41	5.7
Total	5,450	187	3.4 average	211	3.9 average
D. Oil-Circuit-Breaker Bushings					
First	8,076	329	4.1	187	2.3
Second	7,302	287	3.9	114	1.6
Third	6,564	401	6.1	164	2.5
Fourth	1,758	83	4.7	38	2.2
Total	23,700	1,100	4.7 average	503	2.1 average
E. Spare Bushings (All kv ratings and types)					
First	1,034	76	7.0	86	7.9
Second	1,419	168	11.8	117	8.3
Third	1,089	143	13.1	110	10.1
Total	3,562	387	10.6 average	313	8.8 average

Conforming to this procedure for rating insulation we have set up for use in our company "the basic rating for insulation quality" (table III) for the different types of equipment tested. Power-factor limits are given in the upper part of the table and watt-loss values in the lower part. In general, the power factor of good (G) insulation is shown 3.5 to 4% or less; deteriorated (*D*) insulation 3.5 to seven per cent; and remove (*R*) insulation above five to seven per cent.

Similarly, by the watts loss check the corresponding values range as follows: (*G*) 0.1 to 0.2 watt; (*D*) 0.1 to 0.5 watt; and (*R*) above 0.3 to 0.5 watt, again depending on the type of equipment tested.

As the power factor of insulation changes considerably with temperature the above power factor values are corrected to 20 degrees centigrade. A typical temperature power-factor correction curve for transformer insulation is shown in figure 5. The shaded area represents *D* insulation at various temperatures, which permits of ready allocation of insulation-test results obtained in the field. This set of curves was obtained from a

Table VI. Power-Transformer-Bushing Faults Segregated as to Voltage Rating, Summary of Four Years of Field Testing
(January 1934 to October 1937)

Bushing Kv	Test	Number of Bushings Tested	Defective		Remove		Average for 3 Tests	
			Number	Per Cent	Number	Per Cent	Per Cent D	Per Cent R
132	First	278	2	0.7	2	0.7	1.04	0.35
	Second	209	0		0			
	Third	88	4	4.5	0			
88	First	108	10	9.3	9	8.3	7.7	6.6
	Second	58	3	5.2	2	3.5		
	Third	0						
66	First	719	14	1.9	22	3.1	1.8	2.2
	Second	529	8	1.5	5	0.9		
	Third	0						
44	First	744	80	10.8	64	8.6	10.7	8.0
	Second	156	16	10.2	8	5.1		
	Third	0						
33	First	1,490	63	4.2	78	5.2	4.2	4.5
	Second	856	17	2.0	28	3.3		
	Third	336	31	9.2	15	4.5		
22	First	909	29	3.2	29	3.2	4.4	3.0
	Second	569	40	6.3	14	2.5		
	Third	0						
15 and less	First	3,477	51	1.5	78	2.2	1.5	2.3
	Second	2,034	29	1.4	56	2.7		
	Third	391	9	2.3	3	0.8		
Total	First	7,725	249	3.2	282	3.7	3.1	3.2
	Second	4,411	113	2.5	113	2.5		
	Third	815	44	5.4	18	2.2		

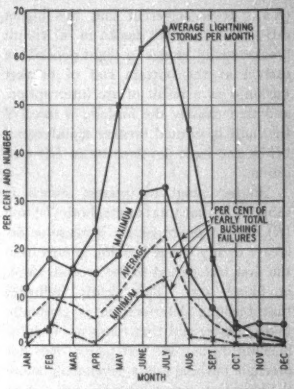

Figure 6. Bushing failures versus lightning frequency, 1932–37

number of tests on actual transformers in service tested at several different oil temperatures, and represents the envelope of power factors of transformers rated (*D*).

In applying in the field the basic insulation ratings given in table III, considerable latitude is given the field-test engineer in assigning ratings where unusual or climatic conditions warrant. Important equipment, or comparatively wide variation in test values between similar pieces of equipment cause him, in some cases, to lower the limits given in the table. Again moist weather conditions and the like will sometimes cause him to boost the tabulated values slightly. Since the test engineer has been specially trained for this work, and is thoroughly acquainted with the problem, we believe the latitude permitted him in applying ratings is more than justified, and is far better than hewing close to an inflexible set of limits. Actual experience has borne out this policy.

VI. Test Results

The field test results summarized and discussed below include some $5^1/_2$ years of testing oil circuit breakers and four years of testing on transformers. Most of the breakers have had three periodic tests and some four tests; the instrument transformers two such tests, and the third is now being made; and the power transformers have had one test, some two, and a few three tests. In the following tables the designation "first," "second," and "third" test refer to the above periodic routine tests. For purposes of clarity the data have been generally segregated into and discussed under three groups: bushings, transformer windings, and internal faults for oil circuit breakers.

Bushing Faults

The summary of faults found in making over 45,000 individual tests on bushings is given in table IV. Bushings in power transformers average, for the three periodic tests, 3.2 per cent rated for removal (*R*); in instrument transformers 3.9 per cent; in oil circuit breakers (for four tests) 2.1 per cent; and in spare bushings 8.8 per cent. Bushings rated defective (*D*), but not sufficiently bad to be removed from service average for the same conditions and locations 3.1 per cent, 3.4 per cent, 4.7 per cent, and 10.6 per cent, respectively. One point of interest in the foregoing figures is the fact that (*D*) and (*R*) faults are roughly of the same order of magnitude except for oil-circuit-breaker bushings where the (*D*) faults are slightly over twice the

Table VII. Power-Transformer-Winding Faults Segregated as to Kilovolts Rating, Summary of Four Years of Field Testing
(January 1934 to October 1937)

Transformer Kv	Test	Number of Transformers Tested	Defective		Remove		Average for 3 Tests	
			Number	Per Cent	Number	Per Cent	Per Cent D	Per Cent R
132	First	179	7	3.9	1	0.56	4.5	0.27
	Second	133	7	5.3	0	0		
	Third	65	3	4.6	0	0		
88	First	52	8	15.2	0	0	16.9	0
	Second	25	5	20.0	0	0		
	Third	0						
66	First	296	26	8.8	5	1.7	8.8	2.3
	Second	227	20	8.8	7	3.1		
	Third	0						
44	First	338	66	19.5	9	2.6	19.1	2.2
	Second	70	12	17.1	0	0		
	Third	0						
33	First	634	107	17.0	28	4.5	19.5	5.0
	Second	344	76	22.0	21	6.1		
	Third	131	34	26.0	7	5.3		
22	First	326	66	20.2	9	2.8	22.0	2.9
	Second	189	47	24.8	6	3.2		
	Third	0						
15 and below	First	83	11	13.3	3	3.6	14.5	3.2
	Second	39	6	15.4	1	2.6		
	Third	13	1	7.7	0	0		
Total	First	1,908	291	15.2	55	2.9	16.1	3.1
	Second	1,027	173	17.0	35	3.4		
	Third	209	39	18.6	7	3.4		

(*R*'s). It is suggested that this higher ratio of (*D*) to (*R*) faults in oil circuit breakers may be due to slight deposits of carbon at the bottom end of breaker bushings as a result of arc interruption, and that usually the bushing is freed of the fault in normal breaker maintenance before the fault develops to an (*R*) condition.

Another point of interest shown in table IV is that total faults, both (*D*) and (*R*), do not progressively increase or decrease in any of the bushing groups from the first test period to the second, third, or fourth test. This clearly indicates that bushing deterioration is gradually taking place, and that removal of faulty bushing during one test period does not preclude bushing faults developing before the next test period some $1^1/_2$ years or so later. In fact bushings rated (*R*) on the second, third, and fourth tests have often been found (*G*) or good on the previous test; all (*R*) bushings have not progressed from a previously found (*D*) fault.

The high percentage of faulty bushings in the spare group is due to two causes: first, the fact that some bushings known to be faulty and ready for the process of reservicing were included in this group; and second, normal storage methods generally used for spare bushings is not particularly helpful in retaining such bushings in first class conditions.

A further analysis of power transformer bushing faults according to bushing type is given in table V. The data represent some 13,000 tests on bushings. The (*D*) conditions range from 0.8 per cent to 8.7 per cent and the (*R*) faults from 0.9 per cent to 5.5 per cent on the average for all three periodic tests. Here again no well-defined tendency is shown for the faults to decrease, stay constant, or increase with each successive test, in any particular type of bushing. It should be definitely pointed out that the data presented in this table should not be construed or interpreted as a quality index of bushings manufactured today. It does indicate, however, the frequency and severity of faults on all bushings as a group on the system involved, and shows clearly where maintenance work should be concentrated to reduce bushing failures.

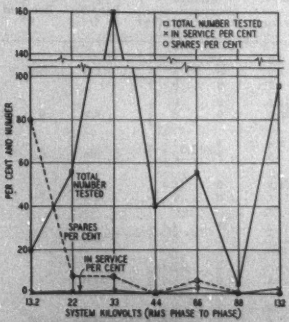
TOTAL NUMBER TESTED
× IN SERVICE PER CENT
○ SPARES PER CENT
PER CENT AND NUMBER
TOTAL NUMBER TESTED
SPARES PER CENT
IN SERVICE PER CENT
SYSTEM KILOVOLTS (RMS PHASE TO PHASE)

Figure 7. Effect of transformer kilovolts on power-transformer-winding faults (R) conservator and nonconservator type; 110 banks (440 transformers)

Table VIII. Internal Faults in Equipment
(May 1932 to October 1937)

Test	Number of Transformers Tested	Defective		Remove		Average for 3 Tests	
		Number	Per Cent	Number	Per Cent	Per Cent D	Per Cent R
Winding Faults—Power Transformers							
First	1,908	291	15.2	55	2.9	16.0	3.1
Second	1,027	173	17.0	35	3.4		
Third	209	39	18.6	7	3.4		
Winding Faults—Instrument Transformers							
First	1,502	451	30.1	113	7.5	35.0	7.8
Second	1,283	497	38.6	98	7.6		
Third	407	163	40.1	36	8.9		

Tank Faults—Oil Circuit Breakers

Test	Number OCB's Tested*	Defective		Remove		Average for 4 Tests	
		Number	Per Cent	Number	Per Cent	Per Cent D	Per Cent R
First	1,346	304	7.5	65	1.6	6.2	1.7
Second	1,217	178	4.9	57	1.6		
Third	1,097	210	6.4	67	2.1		
Fourth	293	41	4.7	10	1.1		

* Multiply by three to obtain number of tanks.

The power-transformer-bushing faults have further been segregated as to voltage class in table VI. The high-voltage 132-kv bushings show the lowest percentage of faults, the 66-kv and 13.2-kv class next lowest and the medium-voltage group the highest. The rather high percentage of faults shown for 88-kv bushings is due largely to the fact that most of these bushings are of old and obsolete designs.

Bushing Failures

It is unfortunate that accurate records are not available to show the decrease in bushing failures over the system before and after the test program was adopted. However, from the rather scattered records available from 1932 to 1937, it is interesting to note how closely the frequency of bushing failure and lightning storms coincide throughout the year. Such a correlation is shown in figure 6. Except for the first three months of the year failures and storms practically increase and decrease together. The relatively high rate of bushing failures in the first three months has been attributed to weather conditions wherein maximum temperature changes exist, frequently associated with the presence of moisture which is an ideal combination of circumstances to open up weak bushing gaskets and permit the entrance of moisture into the bushing. In fact the major number of bushing failures appear to result from the presence of moisture within the bushing.

Internal and Winding Faults

Faults found in windings in some 2,000 tests of power transformers are shown in summary form in table VII. The faulty conditions have been grouped under transformer voltage rating and further broken down to show the trend of faults from one test period to the next. Like the transformer bushings, the winding faults are lowest in the high-voltage windings, lower but still high in the low-voltage class, and highest in the medium-voltage ratings. While the (*R*) faults are in the same general order as bushings, it should be noted the (*D*) faults are much higher, ranging from 4.5 to 22.0 per cent. Again, there is no characteristic trend to prevent the occurrence of faults in other transformers of the group from one test period to another, although the faulty conditions found have been removed prior to the next test.

Internal faults in instrument transformers and in oil-circuit-breaker tanks are shown in table VIII, together with a condensed summary of power transformer winding faults given in more detail in table VII. One important fact, which correlates with the failure operating record, is the high percentage of (*R*) and (*D*) faults shown in instrument trans-

former windings, namely 7.8 and 35.0 per cent average for three tests.

Faults in oil circuit breakers show low (*R*) conditions and fairly high (*D*) percentages. This may be explained in part, at least, by the more frequent servicing of oil circuit breakers than transformers. Although the (*D*) faults are high they are apparently removed by sufficiently frequent periodic servicing before they develop into (*R*) faults.

Transformers in Service and Spares

An analysis of power-transformer-winding faults on the basis of transformer voltage and age is shown in figures 7 and 8. These data were taken from conservator and free-breathing single-phase transformers operated in banks of three units with one spare. So long as the

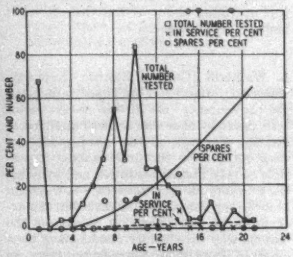

Figure 8. Effect of transformer age on power-transformer-winding faults (R) conservator and nonconservator type; 110 banks (440 transformers)

transformers are in service both types indicate relatively few (*R*) conditions irrespective of voltage rating; but the (*R*) conditions slowly increase with transformer age.

In the spare units, however, a high percentage of (*R*) conditions is indicated in the 13.2-kv class which drops abruptly in the 22-kv class and then slowly decreases as the voltage increases. On the basis of age, the spare units show a large increase in percentage of (*R*) faults after some six years, showing some 25 to 50 per cent faulty units in the age range from 15 to 20 years. Most of these spare units have from the start been held as spares and only put in service as occasion required.

Faulty Gaskets

Faulty and deteriorated gaskets have generally been recognized as one of the major sources of bushing troubles. Some information has been collected in the field on this gasket problem along with the power-factor test work and is presented here.

Figure 9 shows the condition of some 376 bushing gaskets physically inspected in the field on compound filled bushings. These have been rated (*G*), (*D*), and (*R*) with the same understanding as to terminology as applied to bushing faults. It will be noted that after some five years, the gaskets begin to grow faulty at an alarming rate. At the end of some 15 years, 60 per cent of the gaskets are in an (*R*) condition and 30 per cent in a (*D*) condition. Such a record as this leads us to believe that the older type of cork, at least, should not be depended upon in compound filled bushings much longer than five to seven years at the most.

Summary of Power-Factor Tests on Oil Circuit Breakers and Transformers

A composite summary of oil circuit breakers and transformers tested and the average number of faults found during the $5\frac{1}{2}$ years of testing is given in table IX. Several interesting points are brought out in the tabulation: First it is shown that there are 1.52 times as many faulty (*R*) conditions in power-transformer bushings as in oil-circuit-breaker bushings,

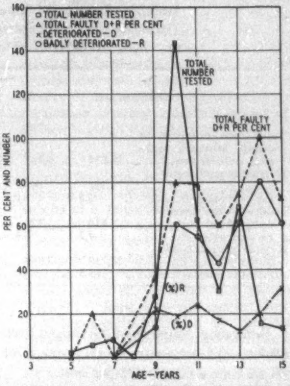

Figure 9. Faulty cork gaskets in compound-filled bushings found by physical inspection, 376 gaskets inspected

and second, instrument-transformer bushings have 1.84 times as many similar faults. The (*D*) faults are shown, on the same basis, as 0.66 and 0.72 times those in oil circuit breakers, respectively.

An analysis of internal faults (*R*) shows ratios of 1.95 and 4.8 for power-transformer and instrument-transformer windings, respectively, compared with oil-circuit-breaker-tank faults. The corresponding ratios for (*D*) faults are 2.6 and 5.6. A study of this table IX indicates clearly where the highest percentage of faults exist.

Fault Distribution by Companies

As the data of fault conditions of insulation presented above were obtained from six different companies, operating in different sections of the country, under different climating conditions, and various requirements, the question may well be asked: "How do the fault conditions compare between the different companies?" A comparison of results on this basis is given in table X. Of the some 60,000 tests reported above, the (*D*) faults ranged from 3.0 to 8.3 per cent, averaging 6.7 per cent; and the (*R*) faults ranged from 0.8 to 3.5 per cent, averaging 2.8 per cent.

It is therefore evident that faulty insulation conditions, both (*D*) and (*R*) faults run in the same general order in all six companies except company (*F*). In this one case it is known that new equipment and a large concentration of the tested equipment in power stations, where maintenance is inherently closely watched, seems to account for the lower fault record.

Table IX. Summary of All Equipment Power-Factor Tested
(May 1932 to October 1937)

Equipment Tested	Number of Tests	Defective		Remove	
		Number	Per Cent	Number	Per Cent
Oil Circuit Breakers	3,950				
Tanks	11,850	733	6.2	199	1.6
Bushings	23,700	1,100	4.7	503	2.1
Power Transformers	3,144				
Windings*	3,144	503	16.0	98	3.1
Bushings	12,974	406	3.1	413	3.2
Spares in storage**	410	125	30.5	82	20.0
Instrument Transformers	3,192				
Windings*	3,192	1,111	34.8	247	7.7
Bushings	5,450	187	3.4	211	3.9
Spares in storage**	242	51	21.0	48	19.8

* All windings of a transformer classed as *one winding*.
** Rating based on over-all condition—winding and bushings.

Table X. Summary of Power-Factor Tests in All Companies
(Including Oil Circuit Breakers, Transformers, and Bushings)
(May 1932 to October 1937)

Company	A	B	C	D	E	F	Total
Total Tests—bushings, oil circuit breakers, tanks and transformers	18,911	6,347	2,925	8,618	19,329	3,685	60,315
Number of equipment:							
Rated *D*	1,580	508	173	694	976	110	4,041
Per cent rated *D*	8.3	8.0	5.9	8.1	4.9	3.0	6.7
Number of equipment:							
Rated *R*	613	155	101	250	523	29	1,671
Per cent rated *R*	3.2	2.4	3.5	2.9	2.6	0.8	2.8
Number of equipment:							
Rated *G*	16,718	5,684	2,651	7,674	18,330	3,546	54,603
Per cent rated *G*	88.5	89.6	90.6	89.0	92.5	96.2	90.5

Equipment found good (*G*) ranged from 89.0 to 96.2 per cent with an average for all six companies of 90.5 per cent.

VIII. Summary and Conclusions

From the data presented above, and other related testing work carried on in the field during the past six years, the following conclusions appear justified:

1. The power-factor test method of determining the insulation quality of high-voltage equipment in the field has proved a most useful and practical tool in permitting a higher grade of apparatus maintenance and in reducing service failure of such equipment.

2. The type of power-factor test set which has been used has proved an accurate, rugged, and reliable instrument in use. The particular features of this set which permit of direct reading of current and watts loss have been particularly helpful in locating faults in equipment shown defective by the over-all power factor determination.

3. It is considered highly desirable, for best results, that the test set be placed in the hands of a thoroughly trained experienced test man who is familiar with the insulation problem, and one who has considerable knowledge of equipment design, maintenance and operation.

4. Insulation faults develop in all types of equipment such as bushings, transformers, wood insulation, and oil regardless of equipment design as it exists today. These faults may develop critically within test period intervals of 18 months to two years, as shown by the experience cited above, and appear, in a few cases, to develop to a lesser degree in a shorter period of time. Periodic testing, therefore, is necessary if a high standard of insulation is to be maintained.

5. Critical insulation faults found on successive tests are not always developments of (*D*) conditions found on the previous test; they often appear in equipment that previously tested good (*G*).

6. Faulty insulation is less frequent in new equipment, but may be expected to develop to a degree warranting some concern within a period not longer than some five years, after which constant periodic checking, or testing, seems desirable if critical faults are to be minimized.

7. Most faulty equipment so far found can be reconditioned with a reasonable amount of labor and expense, and many costly failures thus avoided, if prompt attention is given to (*R*) faults.

8. The classification of insulation faults on a power factor and/or watts loss basis as given in table III above, and servicing them on this basis has proved a reasonable and practical method of greatly reducing service failures on the equipment tested.

9. Insulation faults requiring prompt attention, which develop under service conditions in oil circuit breakers and transformers, as found by our experience, range, on the average over several years, as follows:

Oil circuit breakers, including bushings.....1.6 to 2.1 per cent
Power - transformer windings, including bushings.....3.1 to 3.2 per cent
Instrument transformer windings, including bushings.....3.9 to 7.7 per cent
Bushings in the above three items.....2.1 to 3.9 per cent

10. The economic value of this test work in system maintenance is unquestionable, although it is difficult to express the savings effected in money value done.

IX. Acknowledgments

The author wishes to acknowledge the careful and painstaking field work of Mr. E. W. Whitmer of the American Gas and Electric Service Corporation, and of Mr. F. D. Brook of the Appalachian Electric Power Company in obtaining the field records, and their help in preparing the summarized data in the paper.

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Discussion

H. L. Cole (Westinghouse Electric and Manufacturing Company, Sharon, Pa.): Mr. Gross has made a valuable contribution to the art of power-factor testing in presenting the large amount of data given in the paper. This is particularly true with respect to tests on terminal bushings. The value of power-factor testing of bushings is well established.

In connection with the table of "basic rating for insulation quality," it is noted that a correction is made to bring the measured values to an equivalent 20-degree-centigrade figure. It is thus recognized that temperature plays an important part in the rating of the insulation.

For several years we have recommended lower power-factor limits for bushings operating in hot oil, as on power and distribution transformers. For instrument transformers and breakers, somewhat higher limits are safe. I believe that a basic rating should make a distinction between bushings operating in hot oil and those in oil at ambient temperature.

L. Wetherill (General Electric Company, Pittsfield, Mass.): This paper brings out the advantages of having power-factor tests made by men who are well qualified to exercise judgment in the interpretation of data obtained in the field, making it possible to take immediate action and avoiding the necessity for rigid adherence to a system of arbitrary limits. We believe that the acceptance of this viewpoint is one of the reasons why satisfactory results have been obtained from field power-factor tests on bushings, and doubtless it will prove even more beneficial in connection with other types of apparatus in which the designs are less standardized.

A question is raised regarding the theoretical justification for power-factor tests made on fibrous materials, such as insulating cylinders, between electrodes placed three inches apart on the outside surface. Our experience has been that measurements of this nature offer a particularly sensitive method of detecting the presence of moisture. It would seem that a very small trace of moisture present in fibrous or laminated materials tends to produce a marked change in electrical loss characteristics when the stress is applied parallel to the laminations. If we were dealing with large masses of insulation it would be found that the power-factor measurement obtained with the voltage applied parallel to the laminations would be the most sensitive method of detecting small traces of moisture. In materials such as cylinders, it is rather difficult to make a power-factor test in which the stress is entirely parallel to the laminations, since a test between the ends of a cylinder would permit the stray capacitance to mask the power factor of the cylinder. The method of test used by Mr. Gross, namely, the application of voltage between the electrodes placed three inches apart on the outside of the cylinder, appears to be the most practical method of making a test in which the stress is applied principally parallel to the laminations. It would seem, therefore, that there is adequate theoretical justification for the use of

this test in addition to the support which has been afforded by practical experience.

The curves of figure 6 showing the correlation between failures and lightning storms is quite interesting, but the disagreement of the two curves during the early part of the year suggests that it might be well to examine the correlation between failures and humidity or precipitation. We have known for some time that moisture and lightning were the chief causes of failure, but the curves of figure 6 seem to suggest that both factors in combination are involved in the majority of cases.

Mr. Gross states that the data in his paper are not representative of the bushings which are now being manufactured. A lapse of five to seven years is required before field-test data and experience obtained on a given design begin to acquire great significance. I believe, however, that evidence obtained from developmental tests gives us excellent reason for believing that bushings as now manufactured, will in most cases be found markedly superior to those which were manufactured in past years before the present extensive body of field experience was accumulated.

L. B. Chubbuck (Canadian Westinghouse Company, Hamilton, Ont.): Our company apply routine power-factor tests to all new high-voltage bushings and have carried out extensive field power-factor tests across Canada. We fully agree with Mr. Gross as to the value of field testing, and have found may cases of apparatus showing poor power factor that after cleaning or other minor repairs returned to good operating condition.

During this discussion the point was raised as to whether power-factor tests on high-voltage apparatus should not be made at operating voltage, rather than at approximately 10,000 volts. We have equipped a power-factor bridge with an external condenser of 150 micromicrofarads designed for 100 kv at atmospheric pressure, and up to 187 kv with increased pressure. Due to ionization losses we find power factors obtained with the high-voltage bridge usually run considerably higher than with the standard bridge.

V. M. Montsinger (General Electric Company, Pittsfield, Mass.): In making use of field power-factor data obtained on transformers Mr. Gross is exploring a field in which the complexity and difficulties will undoubtedly be considerably greater and more numerous than those which were encountered when the use of field power-factor measurements on bushings and circuit breakers was being developed. The greater variety of types and designs of transformers will necessarily make the interpretation of the data a task which will call for a high degree of judgment, and it appears that Mr. Gross is making the right approach in this matter.

It would appear that the usefulness of field power-factor measurements on transformers can only be established by the creation of a considerable quantity of operating experiences and test data judiciously interpreted. The information given in this paper should prove significant and suggestive, both to operators and to manufacturers. We would like to raise a number of additional questions which Mr. Gross may be in a position to answer.

1. In tables VII, VIII, and IX data are shown regarding the number (or percentage) of power-transformer windings which were deemed to be in a condition requiring removal from service. It would be desirable to know whether or not subsequent examination verified the presence of definitely undesirable conditions in approximately all of these cases or if there was an appreciable number of cases in which subsequent examination disclosed no defect.

2. In cases where definite defects in transformers windings were found after removal from service, is it possible to indicate the approximate proportion of cases of undesirable conditions falling into the following classes?

A. Presence of water in insulating oil.

B. Presence of water in solid insulating materials.

C. Deterioration of oil.

D. Deterioration of solid insulating materials.

E. Failure or breakdown.

3. Were there any other major causes of defects not covered by the previous question?

4. In the case of transformers removed from service, was it found possible to carry out a reconditioning permitting them to be restored to operation, and if so, what type of reconditioning was used?

5. In how many cases were repairs necessary other than reconditioning mentioned in (4)?

6. Table IX indicates a higher percentage of transformers for which removal was recommended under spares than under active units. Were the types of unsatisfactory conditions found in the spare units essentially the same as those found in the active units, or was there a greater preponderance of a different type of unsatisfactory condition in the spare units as compared with the active units? Were spares modern transformers or old transformers?

It is, of course, well known that high power factor does not always mean low dielectric strength of insulating materials. For any given material or configuration there are, however, normal power-factor characteristics, and any wide deviation from these normal characteristics is indicative of some physical change which usually deserves investigation, and quite possibly correction. Increases in power factor may be caused by chemical contamination, oxidation of oil, or by absorption of moisture. For many types of apparatus it would appear that operating experience has shown that appreciable increases in power factor are usually related to the third of the three causes listed above. This would appear to be a sound justification for the use of field power-factor testing, when, as recommended by Mr. Gross, adequate judgment is exercised in interpretation of the data.

It would be interesting to know if Mr. Gross during his investigation has had an opportunity to obtain any relative power factors on a given transformer or transformers. Our experience in measuring insulation resistance of transformer windings leads us to believe that, when working with insulation structures having such a variety of configurations, relative power factors may be more valuable than actual values.

We are in sympathy with any method which aids in detecting incipient faults in transformers. At the present time power factor measurement appears to give promise, although it will need to be developed with considerable care in order to avoid the possibility of drawing false inferences by comparison of readings obtained on units of different design and characteristics.

Harold Goodwin, Jr. (Wyncote, Pa.): The paper is very valuable in making known the results of a large number of tests on particular types of insulation by a particular method. The factors obtained can be used in further practical applications of the method. But the mere presentation of the results raises in the mind the questions: "Why?" "How does the current flow to give the results indicated by the instruments?" The oral discussion and the contributions by some specialists on cable also indicated these questions. The cable specialists might join in the search very diligently as they may get some help for their problems from the solution of the bushing problem, just as I hope the bushing specialists may get some help from the telephone engineers, as I shall point out below.

Compound-filled bushings which have failed in service or which have tested defective and been removed and tested to destruction have, from my observation, generally indicated one basic type of failure: the compound has tended to separate from the porcelain rain shield, leaving a fissure that is likely to be somewhat conducting due to dampness or carbonization. But until final failure is closely approached there is not a complete path from one pole to the other. There is rarely a direct short path at the point of maximum stress or elsewhere. If this is so: what causes the increase in watts loss and power factor in the bushing with the incipient defect?

A theory developed by the writer in 1930 to explain the observed results was, very briefly, this: The moist fissure between the compound and the porcelain acts as the plate of a condenser with the conductor the other plate. Therefore the bushing draws more current than a good bushing. But why has the power factor also increased? This is due to the resistance of the condenser plate itself, the moist fissure. The energy is not then lost *throughout* the bushing insulation but only in the fissure. The current flowing to the far part of the fissure must flow through the resistance of the near part of the fissure connecting it to a terminal.

The probability of the correctness of this theory was shortly confirmed by the presentation to the Institute of a paper on telephone insulators showing exact studies of a similar phenomenon. This paper by L. T. Wilson of the American Telephone and Telegraph Company is entitled: "A Study of Telephone Line Insulators," and can be found on page 1536 *et sec.* of the TRANSACTIONS for 1930. The paper should be studied by anyone interested in this subject. I shall not try to review it here but want to point out that the loss here considered is just one of seven discussed in this paper, and—this is most interesting—some of the other losses seem to have a close resemblance to losses that are occurring in oil-filled bushings and which cannot be ac-

counted for by the theory set forth above. This telephone-insulator paper is also recommended to the cable specialists as similar theory may be helpful in explaining some things that are now rather obscure.

A most interesting thing about the theory set out above and the further results of the telephone insulator study is the indication that the power-factor method detects a failure or defect by observation of factors that are incidental to the development of the final fault rather than by measurement of the degree of final failure which may yet be almost infinitesimal. In cases where this is so, it is logical to conclude that the apparatus may be much more safely reconditioned without reinsulation than if the final fault had proceeded to measurable proportions.

Since no exact work, similar to that on the telephone insulators, has to my knowledge been done on the subjects of this paper, bushings and transformer windings, I shall not go to further length to expound this theory, but present it for those particularly interested to take up, test and present to us in complete and verified form.

G. B. Tebo (Hydro-Electric Power Commission of Ontario, Toronto, Ont., Canada): Mr. Gross has added materially to the already extensive records of power-factor tests on insulation, and has reached conclusions similar to those previously reported. The grand total of 60,000 tests appears to lend some weight to these conclusions but the absence of any data to show reduction in failures due to power-factor tests is rather disappointing.

There still appears a need for more critical discussion of the significance of power factor in rating the serviceability of an insulation. It can be shown that a bushing may be on the verge of failure without appreciable increase in energy loss or power factor; also that a substantial increase in power factor can be obtained without any increased hazard. In table III Mr. Gross recommends removal of any bushing having more than 0.5 watt loss at 10 kv. It is evident that a loss of 0.5 watt, per se, is not hazardous in a bushing weighing several hundred pounds. Some distinction should be made between energy losses uniformly distributed throughout a bushing, and those which cause serious disturbance in potential gradient and consequent overstress on the remaining good insulation.

The "hot collar" test referred to, was used by the writer in 1936, and as Mr. Gross points out, it is distinctly superior to the over-all power-factor test. Such faults as cracked and porous porcelains, entrapped water, etc., may be located by a "step-by-step" test but may not affect the over-all power factor appreciably.

The advantages claimed for the "hot collar" test are still restricted by the low test voltage (10 kv), the complex testing equipment and the necessity for interruptions on all equipment tested. Mr. Gross stresses the need for employing specialists in power-factor testing and interpretation of results. Such requirements may be related to the complexity of the testing technique.

The potential-gradient test (described in *Electrical World*, May 8, 1937) was developed to utilize the advantages of a step-by-step procedure and at the same time to provide a simplicity of equipment and technique comparable with that used in live-line insulator testing. During the past two years, the potential gradient test has been applied to about 2,500 bushings operating at 10 kv to 220 kv. Annual failures in this group have been reduced from an average of 15 in 1935 and 1936 to two in 1937 and none in 1938. Both bushings which failed in 1937 were abnormal when tested, but failed before removal.

Having thus practically eliminated failures of bushings by means of an annual live-line test, there appears little justification for tests to disclose defective lift rods, inferior oil, etc., which faults are detectable by the present visual inspection and oil testing schedules.

Considering the wide variations in power factor of the various material used for transformer-winding insulation, an attempt to rate the serviceability of the over-all insulation in terms of power factor seems rather arbitrary. It would be interesting to know how many of the 345 transformers showing power factors calling for "removal" were actually removed, and what faults subsequent inspection disclosed.

E. J. Rutan (Consolidated Edison Company of New York, Inc., New York, N. Y.): A study of the tables in this paper indicates that the limiting values of power factor selected for the different pieces of equipment can only be arrived at by the accumulation of considerable data. From several of the discussions which have already been presented, it would seem desirable to call attention to the fact that these tests have, in general, been made at less than rated voltage. The author's results do show when using the limits selected improvements in the condition of equipment classed as defective have resulted from overhauling. It does not follow, however, that the tests as at present conducted are giving the best clue to possible defects.

I think we can justify this statement from experience in dielectric tests of cable and other apparatus. In cable testing, the existence of ionization causes a very material difference in the power-factor readings obtained. In the Consolidated Edison Company over the past few years, we have been doing considerable work on certain pieces of high-voltage apparatus and insulators to detect what we have called, "the voltage of corona initiation." These measurements were started following an operating failure and to our surprise indicated that some equipment showed evidence of corona discharge at below normal operating voltages. Since then, this test has been included as part of the regular acceptance for certain types of insulation.

In view of the fact that in the power-factor measurement for the detection of possible faults we are looking for abnormal conditions, it is reasonable to expect that as faults develop there might be corona conditions at operating voltages. These same units, when new, might not show corona or ionization until several times normal voltage had been applied. It would seem, therefore, that measurements made at normal voltage would be more likely to disclose the development of undesirable faults. It might also be expected that the power-factor limits distinguishing good from defective equipment would be better defined.

In the past, the writer's organization has made a few power-factor measurements and efforts were always made to test at rated voltage. It is recognized, however, that there are difficulties encountered which at the present time have not been overcome. This, however, should not deter those who are regularly making these measurements from attempting to obtain data at rated voltage. Until this field has been explored, it is the writer's opinion that we will not fully realize the benefits of this type of measurement for diagnosing insulation troubles.

F. J. Vogel (Westinghouse Electric and Manufacturing Company, Sharon, Pa.): Mr. Gross' paper furnishes data showing the results of several years' experience in field testing and is of great value both to operators and manufacturers. These results show shortcomings in materials used and in design practices. They also show the desirability of using checks to keep apparatus in good operating condition and avoid failures and expensive repairs and loss of service in the field.

There are several factors in power-factor testing of transformer insulation which I would like to mention. The company with which I am associated made power-factor tests for a period of a year or so in the factory on power transformers. The purpose of this was to accumulate data as to what power factors might be expected on new equipment. Due to the careful processing and drying out in the factory it might be expected that the results of the power-factor tests would be fairly uniform and to be, therefore, of little significance. This was actually found to be the case. For this reason the use of power-factor tests has been discontinued on transformers. It might also be pointed out that the power factor varied somewhat with different designs in such a way that the method is not suitable for factory testing.

It might be desirable to call attention to the fact that in service high power factors are not always caused by moisture. Oxidation and oil deterioration lead to high power factors in the oil even though dry. It is of interest that high power factor due to this cause does not result in any loss of dielectric strength. This has been demonstrated by tests on sample barriers ranging from very low power factors to 40 or 50 per cent power factors. Both 60-cycle and impulse tests showed no change with power factor.

It is of great interest that spare units not excited may deteriorate due to moisture. This might be expected particularly in transformers breathing to the outside atmosphere whether directly or in combination with an expansion tank. Where oil has been heated slightly above atmospheric temperature it has been found that it will keep fairly dry. Oil, however, which may become colder than the atmosphere and is in direct contact with the atmosphere can condense moisture and gradually become quite wet. Even transformers which breath in air through a calcium chloride breather may become quite wet due to the oxidation of the oil forming water which is not easily removed.

Mr. Gross has also called attention to the deterioration of cork gaskets. This material was the best material we knew of some

years ago for use as gaskets. It is of interest that materials have recently been put into use which promise to deteriorate very little and which may last indefinitely.

F. C. Doble (Doble Engineering Company, Medford Hillside, Mass.): The paper by I. W. Gross summarizing authentic and instructive information from more than five years of consistent field testing of bushing and transformer insulation by the power-factor method is a credit to the author and should be of value to those in the industry who are responsible for the maintenance of high-voltage insulation.

It is significant that a 10-kv 60-cycle test has been adequate to maintain a completely reliable operating schedule on equipment rated from 13 kv to 132 kv.

Early in the development of field testing by the power-factor method, some insulation engineers felt that a 10-kv test voltage would be entirely inadequate for testing equipment rated by voltages higher than 10 kv. Also some others felt that an off frequency even up to 1,000 cycles would be desirable in order to get away from certain difficulties due to induction from parts of the 60-cycle system other than those under test and to mitigate possible loss effects due to the action of low frequencies on composite insulation.

The paper under discussion typifies a wide experience with dielective loss tests in the field correlated with failures of insulation of all voltages up to and including 220 kv that has proved conclusively that a 10-kv 60-cycle dielectric and power-factor test is adequate for a reliable economical maintenance program.

Referring to Mr. Montsinger's discussion, I agree with his statement that the greater complexity of construction and increased variety of designs of transformers as compared to bushings makes it more difficult to interpret the results of power-factor tests into a reliable transformer-maintenance program. However, I believe that it is not too optimistic to expect that a reasonable degree of standardization of test values can be derived in view of the very simple tables that now cover the entire bushing range that was thought to be just as hopeless some years ago when field test by power factor first began.

Pertinent to Mr. Montsinger's request to the author for an explanation of the fact that spare transformers deteriorate at a much higher rate than those in service I believe that more attention should be given to the electrical characteristics of water in oil. Recent investigations indicate that it is possible for water to be present in oil in a low-loss form that is not revealed by ordinary electrical tests, such as dielectric breakdown or power factor, to a much greater degree than is shown by the literature that describe this phenomenon.

In this low-loss form the water is no apparent handicap to electrical operation. However, a drop in temperature may cause the water to change its electrical character so that it becomes high-loss water which may be a serious operating hazard. The spare transformers pass through a much wider temperature cycle than corresponding transformers in service with a resulting tendency to faster deterioration in a given time.

I. W. Gross: The numerous discussions given of this paper indicate the subject of field testing of insulation is a very live one at the present time.

The question of correcting power-factor readings to a standard temperature and the methods for so doing is one on which we have spent considerable thought and time. Mr. Cole has pointed out that he has taken this into account by using different power-factor limits on bushings, depending on the temperature of the oil in which the bushing is located. Another method on which we have been working is that of assigning a temperature to the bushing on the basis of the composite parts which are at different temperatures. For example, the bushing temperature may be rated on ambient air, copper temperature at the top of the bushing, or oil temperature of the apparatus in which the bushing is located; or in the case of oil-filled bushings it may be based on the temperature of the oil in the bushing. Undoubtedly, some further study in refinement is possible in arriving at the most desirable basis for temperature.

Mr. Wetherill has pointed out the theoretical justification for the test on fibrous insulation parallel to the fiber structure. It is quite fortunate from a practical point of view that this test along the fiber, such as along the surface of cylindrical insulating members, has proved to be an adequate test to detect the presence of moisture, as it would be decidedly burdensome and complicated to make routine tests radially. While it is true, as Mr. Wetherill points out, that the highest per cent of bushing failures (figure 6 of paper) occurs during the lightning season, it is also true that in the cases of bushing failures in the early part of the year when general weather conditions are cold, with subsequent thawing and rain, there is a rise in bushing failures which indicates to us the possibility that moisture, which had entered the bushing prior to failure, had become destructive by penetration into or through the insulating material. As pointed out in the paper deteriorated gaskets are contributory factors under severe weather conditions. Several years ago we experienced a number of bushing failures immediately following a protracted cold spell followed by thawing and rain in the early part of the year. These failures were not accompanied by lightning but appeared to be due to deterioration of the bushing by the entrance of moisture under severe weather conditions.

Mr. Montsinger and others comment that the type of transformer design may affect the interpretation of power-factor readings. This point is well taken and, as pointed out by him, undoubtedly a large number of tests on different types of transformers will be required before we can determine transformer faults with the same certainty that is now possible with bushings. However, the work which we have been carrying on during the past few years seems to indicate, with our present knowledge of the art, that there are many other factors in the detecting of transformer faults which at the moment far outweigh the difference in transformer design. This point, however, should be given further consideration.

In answer to Mr. Montsinger's question regarding the types of faults which have been found in transformers, so far as we have been able to determine, these faults have been due to the entrance of moisture into the transformer and have in most cases been successfully removed by drying the transformer by conventional, recommended methods. With practically few, if any, exceptions, we have not discovered other types of faults in such defective transformers at the time they were serviced as a result of the power-factor test.

In many cases, of course, the oil has deteriorated where it has been in service for some length of time, and on reservicing, it is always reconditioned or replaced. I do not recall that we have had any cases of seriously deteriorated insulation attributed to anything except absorbed moisture.

As brought out by many of the discussers, there is undoubtedly a great deal of research work to be done in studying the deterioration of insulation in a complicated, composite structure such as a transformer winding with its insulation of conductors, sections, cores, etc., and it is hoped that a well organized and carried on study of this problem will be made in the future.

The deviation of power factors, concerning which Mr. Montsinger asked, is very valuable in determining the condition of transformer insulation in the field, not only by comparison of insulation between transformers of the same design, manufacture, rating, etc., but also by comparison of insulation between primary and ground, secondary and ground, and interwinding insulation. We have sometimes detected faults by comparisons of this type.

Messrs. Chubbuck, Rutan, and Doble have all commented on the power-factor testing on higher voltages than 10 kv employed in our work. As pointed out by Mr. Doble, studies made so far indicate that 10 kv is adequate for the purpose. It is to be expected, however, that at higher test voltages approaching the operating voltage of the equipment, corona formation may be detected in some cases. This, however, with our present experience with practical field testing seems to be more a question of insulation design than one of equipment maintenance.

It should not be lost sight of, too, that to attempt to test field equipment which ranges all the way from 2,300 volts up to 230 kv would undoubtedly require considerably more elaborate test equipment as regards voltage supply than has generally been considered practical in the field. Unless there is some distinct advantage, which so far has not been apparent, to be gained by the use of high voltage in the order of 100 kv or so, we believe it is a better plan to retain a practical working limit of voltage until such time as research developments show that a higher voltage is essential to the satisfactory maintenance of equipment.

Mr. Goodwin's theory on the reason for failure of compound-filled bushings is quite interesting. A number of other theories have, of course, been set up, discussed and explored in the development of the present test set which we are now using.

Mr. Tebo touches on several points of interest as regards testing procedures, methods, equipment, and results obtained. In the first place, while the paper did not report numerically the reduction in failures of bushings or other equipment since power-factor testing work was started, there is abundant evidence to show that material reductions have taken place. This infor-

mation, however, is not in the form of statistical, numerical data, but rather comprises the frequency of complaints from the field of equipment failures and also the verbal reports of the different properties on which testing work has been carried on. In fact, at the present time we are using three test sets in an attempt to carry out a yearly test schedule on oil circuit breakers, bushings, and transformers, and the results of testing have been so successful in improving the operating performance of equipment that we from time to time receive urgent requests from the field that the schedule be hastened to take care of testing their equipment on a more frequent basis to forestall trouble.

While, as pointed out by Mr. Tebo, it is theoretically possible to set up conditions of faults in bushings where a serious operating hazard can exist on a bushing without an appreciable increase in energy loss or power factor, still we should not lose sight of the fact that experience seems to show that actual occurrences of this kind are very infrequent. Likewise, the theoretical consideration of a $\frac{1}{2}$-watt loss at 10 kv in a bushing may exist without the bushing being a hazard on the system must be correlated with the practical experience obtained in testing bushings where losses of such magnitude are found and inherent faults in bushings have been detected. The possibility of these two conditions existing is, of course, admitted, but their probability seems remote.

Regarding the hot-collar test referred to in the paper, Mr. Tebo has apparently misunderstood our opinion of its place in test work and the importance of this type of test in detecting faults. It is not our opinion that this type of test is superior to the over-all power-factor test. It is merely a supplementary test which, when used in conjunction with the over-all power-factor test, has been useful in detecting some types of faults in particular types of bushings. This hot-collar test, so far as we know, was first described by Mr. O. E. Fawcett of the West Penn Power Company early in 1936 and was first used on our property subsequent to this.

Further, Mr. Tebo's implication that the testing technique which we are employing is complicated and therefore requires "specialists in power-factor testing and interpretation of results" is an opinion with which we quite emphatically differ. It often happens that a test device which requires merely the turning of a handle and the reading of an instrument scale falls far short of obtaining satisfactory results unless the results are understood and analyzed by competent and skilled men.

Considerable advantages result by having the tests promptly interpreted and remedial measures taken at the time of the tests. Mr. Tebo's statement that failures have been practically eliminated on some 2,500 bushings tested by the potential-gradient method warrants some comments. The absence of failures in 1938 (which is approximately only half of the current year) and the fact that the two which failed in 1937 were abnormal when tested leave the results very inconclusive. It should be borne in mind that to remove from service all bushings which are merely "abnormal" on test would place a heavy financial burden on the operating company which could not be tolerated. The degree of abnormity must be evaluated in terms of operating hazard. It is often true that an attempt to draw conclusions from incomplete data is often more harmful than beneficial.

We question the ability of any test method to eliminate all failures of bushings in service. If it should be possible to accomplish this, Mr. Tebo's statement that "there appears little justification for tests to disclose defective lift rods, inferior oil, etc.," is not in accord with operating experience in our company where we have found defective lift rods by the power-factor test and have eliminated them before breaker failure has occurred. The importance of field insulation testing lies in testing all major equipment, if possible, rather than to confine the tests to only a small part of it such as the bushings alone.

One type of fault the potential-gradient method applied to bushings cannot detect is faulty conditions of the insulation on the bushing within the apparatus, that is, below the bushing mounting flange. Faults of this type have been found by the power-factor method.

Mr. Vogel points out that a high power factor of the oil does not affect the insulation, and we presume he has in mind that if the fault should be localized in the oil (in a transformer), then servicing the oil would be a suitable means of reconditioning the transformer. This indeed is an interesting point, but it should be borne in mind that if the high power factor of the oil is due to contamination by moisture, then over a period of time that moisture may have worked into the insulation and become concentrated at some point in the insulation structure which is vital to the successful operation of the equipment.

In closing this discussion there is one broad point of view that we wish to emphasize, and that is, in field testing of insulation of the type described in the paper, we are dealing with a most complicated structure consisting of oil, paper, fibrous insulation, wood, etc. In many cases it is fortunate indeed that a power-factor test does give us an indication of the condition of the insulation as compared with the insulation of that equipment when initially new even though we do not know all the theoretical reasons why it does. Those who choose to take chances in operating a system with insulation known to be far different from what it was in its original condition must, of course, run the risk of equipment failure. Just how bad such insulation may become, and still result in satisfactory operation of the equipment is a point which is not known at the present time, but it is hoped that as our test work continues, it will be possible to obtain some valuable information on this point over a period of time.

A Self-Checking System of Supervisory Control

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Synopsis: This paper describes a new type of supervisory control system which was developed to reduce the selection time in large, multistation applications. The principles are based on the use of short and long electrical pulses and circuit designs not requiring a check-back code for assuring accuracy. It is equally applicable to a two-wire telephone line or a carrier-current channel. The design is quite flexible, permitting many alterations and additions to satisfy local conditions peculiar to its problems. The theory behind the elimination of the check or selection is explained.

MOST modern systems of supervisory control are based on the logical principle of checking a selection before performing an operation. To do this, a checking code duplicating the selecting code is returned from the substation to the dispatching office. This insures that the desired unit has been correctly selected for operation.

The self-checking system, here described, obtains the same assurance of correct selection without the necessity of returning a duplicate of the selecting code. Thus, the over-all selecting time is reduced, particularly in the larger multistation systems. The usual initial operation of station selection is also eliminated since we can look at the whole system as a single station. Each remote piece of apparatus is assigned a definite code. The resulting saving of time is important, particularly when a carrier-current channel is used, since it minimizes the time during which outside interferences can tend to disturb or mutilate the signalling sequences.

In the design of the self-checking system, two types of selecting pulses are used. They differ from each other in their length or in the time of energizing the line. The short pulse has a characteristic time of the order of one-tenth

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of a second. The long pulse is purposely lengthened to approximately three times the time element of the short one.

Each selecting code is made up of the same number of total pulses and the same number of long pulses. By this means, the possibility of incorrect selections is eliminated. The explanation of this will be apparent from the circuit descriptions to be discussed later.

In the smaller applications, there is no advantage in the self-checking system. As the number of total pulses increase, the number of possible selection combinations enlarge enormously. This is apparent from figure 1. It is for this reason that the self-checking system is economical and most beneficial where there are many operations and several substations to be controlled and supervised.

From a given number of total pulses, the maximum number of selection combinations occur when the number of long and short pulses are equal. As an example, let us consider the case where eight pulses are used. The formula for determining the total selections may be written:

$$N = \frac{T \times (T-1) \times (T-2) \ldots (S+1)}{L \text{ (factorial } L)}$$

where

N = total number of selections
T = total number of long and short pulses
L = total number of long pulses
S = total number of short pulses

In this case, should three long pulses be used, the number of shorts would necessarily be five.

$$N = \frac{8 \times 7 \times 6}{1 \times 2 \times 3} = 56$$

However, should there be four long pulses, we have

$$N = \frac{8 \times 7 \times 6 \times 5}{1 \times 2 \times 3 \times 4} = 70$$

Should five long pulses be employed, we arrive at the same total as with three.

$$N = \frac{8 \times 7 \times 6 \times 5 \times 4}{1 \times 2 \times 3 \times 4 \times 5} = 56$$

If our system were composed of approximately 50 units, the scheme using three long pulses would be used since less total time is required.

Where ten total pulses are required, four long pulses permit selecting any one of 210 units. On the basis of 0.1 second for a short and 0.3 seconds for a long pulse, it is apparent from the foregoing that with an increase in selection time of 0.4 seconds, the size of the system may

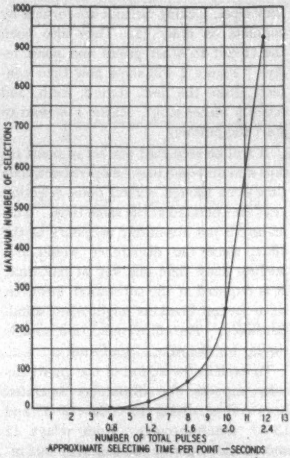

Figure 1. Curve showing the selection time in seconds for any unit out of a known maximum, given a code with a definite total number of impulses

increase from 56 to 210 points. Due to the natural limitations of the number of contacts available on standard relays, less than the full theoretical number of selections is practical. The usable codes, even in the larger systems, are at least half of the theoretical total.

An even number of total pulses is advisable for purposes of balanced circuit design. Also, an even number of long pulses is preferable to an odd number. In the circuit design, the first half of the total pulses is called the group selection, while the second half is known as the point selecting pulses. For example,

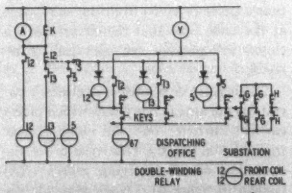

Figure 2. Code set-up circuit outlining method of establishing a definite code

consider the case where a total of ten pulses is used. If the total number of system points is 100, the codes would be assigned so that there would be two long pulses in each of the first and second groups of five pulses. Using a system of numbering whereby the numbers represent the long pulses, code 14–79 would mean that the first, fourth, seventh, and ninth pulses were long while the remaining ones were short.

The group codes would be 12–13–14–15–23–24–25–34–35–45.
The point codes would be 67–68–69–60–78–79–70–89–80–90 (the 0 denotes the tenth pulse).

This represents a ten by ten layout or 100 total points.

The codes would be:

12–67	13–67	14–67	15–67	23–67
12–68	13–68	14–68	15–68	23–68
12–69	13–69	14–69	15–69	23–69
12–60	13–60	14–60	15–60	23–60
12–78	13–78	14–78	15–78	23–78
12–79	13–79	14–79	15–79	23–79
12–70	13–70	14–70	15–70	23–70
12–89	13–89	14–89	15–89	23–89
12–80	13–80	14–80	15–80	23–80
12–90	13–90	14–90	15–90	23–90
24–67	25–67	34–67	35–67	45–67
24–68	25–68	34–68	35–68	45–68
24–69	25–69	34–69	35–69	45–69
24–60	25–60	34–60	35–60	45–60
24–78	25–78	34–78	35–78	45–78
24–79	25–79	34–79	35–79	45–79
24–70	25–70	34–70	35–70	45–70
24–89	25–89	34–89	35–89	45–89
24–80	25–80	34–80	35–80	45–80
24–90	25–90	34–90	35–90	45–90

From this, it is apparent that the selecting time of any one unit is the same as that for any other unit in the same system, since each code must contain the same number of long and short pulses.

The order of preference of reporting the codes in case of more than one attempt to start at the same instant is determined by the long pulses. The code with the first long pulse will take preference over one having a short pulse at that time. This is also true in multistation layouts where the station which is sending a short

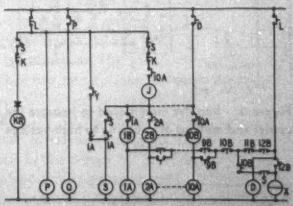

Figure 3. Simple short-pulse counting scheme used for recording the short pulses in a given code

pulse locks out if some other station is sending a long pulse. All points have "storage" circuits so that there is no possibility of losing an indication under such circumstances.

The first application of this system was

made on a pair of 287-kv power lines approximately 270 miles in length. The line circuit consists of a carrier-current channel of 60 kilocycles. Connections to the lines were so made that operation is possible even though either transmission line is open circuited or grounded.

In this case, ten total and four long pulses are used. However, the number of required operations demanded that the codes have up to three long pulses in either the group or point codes. When the group has one long pulse, the point must contain three, etc.

This application has many other features individual to the local conditions and these will be omitted in the general description to follow. There are two dispatching boards, one at Boulder Dam and the other at Los Angeles, on which all operations must report simultaneously. Should the Los Angeles board fail to receive a signal due to any cause, the dispatcher at Boulder is automatically notified. Again, interlocking is used so that the dispatcher cannot attempt a wrong operation. Thus, it is arranged so that a ground switch cannot be closed at one end of a line section if a line disconnecting switch is closed at the other end. Such are examples of special circuits which may elaborate on the fundamentals as will now be described.

Description of Scheme of Selection

Figure 2. As the dispatcher operates a point selection key (key 12–67, for instance) a circuit is completed through the operating coils of relays 12 and 67. As

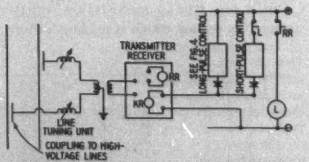

Figure 4. Impulse circuit used to impulse the carrier and method of coupling to high-voltage lines

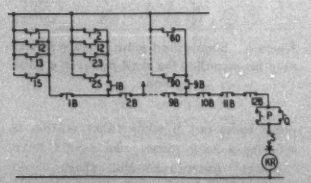

Figure 5. Long-pulse control scheme showing method of inserting the long pulses in their proper position in a given code

they close, locking circuits are formed by contacts on relay 12. They also open the circuit to other group and point relays. Figure 4 will show how their contacts make the first, second, sixth, and seventh pulses long. Relay *Y* is used to start the pulsing.

It will be seen that one set of point relays and only one may be operated at one time even though several point-selection keys are operated at the same time. This feature is not absolutely necessary at the office since the dispatcher would not operate more than one key at one time. It is required at the substation, however, since several breakers might open simultaneously. The office connection is made similar for the sake of uniformity.

To explain the action of the guard circuit, suppose the dispatcher operated keys corresponding to codes 12–67 and 13–67 simultaneously. Both relays 12 and 13 may operate momentarily but relay 12, being first in order, opens the positive feed to relay 13 so that only relay 12 can remain operated over its locking winding. The selection keys are thus wired in series sequence so that only the first one in the sequence is operated.

It will be noted here also that the numbers of the relays operated correspond to the numbers of the pulses which are made long. Should a code be operated which requires three long pulses in either the group or point sections (code 123–6 or 5–890, for example), the second windings of the necessary relays are connected in series by contacts of the point selection key which corresponds to that particular code.

Figure 3. When relay *Y* operates, a circuit is closed to relay *S* or sending relay. Being connected through a break contact of relay *L*, this circuit is effective only as long as relay *L* is de-energized, so that a pulse received from the substation at the same time that the circuit for *S* is closed will prevent the operation of relay *S*.

When relay *S* operates, it closes a circuit for the keying relay *KR*, which places carrier current on the high-voltage transmission lines. This results in the operation of all receiving relays (*RR*) (shown in figure 4). Neglecting for the moment the sequence of pulsing and the control of the long pulses, relay *L* is caused to pick up and drop out with the carrier-current pulses.

The pulses are counted by the counting relays 1*A* to 10*A* when relay *L* is energized and by relays 1*B* to 10*B* when relay *L* is de-energized. The first operation of relay *L* energizes relay *D* as well as 1*A*. Relay *D* is slow releasing when de-energized and does not drop out between pulses.

As long as relay *L* is operated, relay 1*B* is short-circuited and cannot operate even though the contact of 1*A* has completed its operating circuit.

When relay *L* releases after the first pulse, the shunt across relay 1*B* is opened and relay 1*B* picks up in series with the operating coil of 1*A*. As relay 1*B* operates, it transfers the *L* circuit to 2*A* so that it operates in response to the second pulse. Relay 2*B* operates as *L* drops out at the end of the second pulse. The remaining relays of the counting chain operate in the corresponding manner as the pulsing continues.

Figure 4. This shows the sequence of pulsing the carrier current. From figure 3, the keying relay *KR* was energized by the contact of the sending relay *S*. The contacts of the keying relay complete the transmitter oscillator and amplifying circuits thus applying carrier energy to

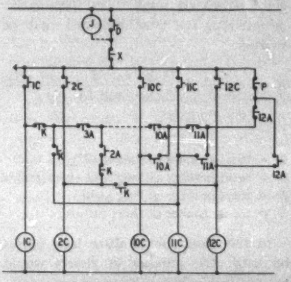

Figure 6. Long-pulse counting circuit used to record the position of the long pulses in a given code

the lines. All receiver relays pick up and, in turn, energize relay *L*. As relay *L* operates, it not only advances the counting chain of figure 3, but opens the keying relay circuit. As the keying relay drops out, carrier energy is removed from the transmission lines, resulting in the de-energization of all receiver relays. Thus, the counting chains in all stations step ahead simultaneously. The function of the long pulse control of the keying relay will be evident from figure 5. Even though the short pulse circuit is opened by relay *L*, a long pulse keeps the keying relay energized and carrier on the high-voltage carrier-current circuit.

Figure 5. For selection purposes, four of the pulses must be long. This is accomplished over long-pulse control circuit which also operates on the keying relay. To transmit code 12–67, pulses number 1, 2, 6, and 7 must be made long,

while the other pulses, that is, 3, 4, 5, 8, 9, and 10, must be short. As soon as relay *S* is energized, a circuit is completed by the make contact of relay 12 to the keying relay *KR*. Relays *P* and *Q* are normally energized through a break contact of *L*. These relays are slow to release and do not drop out immediately when relay *L* is energized. Carrier energy is thereby kept on the line and all relays *RR* and *L* remain energized. After a predetermined interval of time, relay *P*, whose circuit is opened by relay *L*, drops out and opens the circuit of slow-releasing relay *Q*. Relay *Q* also drops out after a certain time and opens the circuit of the keying relay *KR*, thus removing carrier from the line and dropping relays *RR* and *L*. Thus, each one of the four long pulses energizes the keying relay for a definite period of time.

Figure 6. As relay *P* drops on the first long pulse, it operates a long pulse register relay 1*C*. This takes place at the sending station and all of remote stations. The duration of the long pulse is increased by the drop-out time of relay *Q* in order to give the remote stations sufficient time to operate the *C* register relays and to take care of unequal dropping times of the various *P* relays in the other stations. Other long pulses are under control of relay *P* in the same manner. Thus, during the third, fourth, and fifth pulses (of code 12–67) no circuit is completed for the *KR* relay in the long pulse control circuits, and relay *P* has no opportunity to drop. Register relays 3*C*, 4*C*, and 5*C*, therefore, cannot operate. The same is true of 8*C*, 9*C*, and 10*C* of this particular code. At the end of the tenth pulse, all stations would have relays 1*C*, 2*C*, 6*C*, and 7*C* operated and no others. As relay *L* picks up on the tenth pulse, relay 10*A* opens the circuit to relay *KR*, so that no further pulses can be transmitted. (See figure 3.) Relay *D*, receiving no further pulses from line relay *L*, releases after a short interval and opens the original holding circuit for the counting and code relays. Since ten pulses have been received, these relays are held up through the winding of relay *J*. Relay *J* closes through this circuit and operates the point selection relay *B* or *F* (*B* is at the office and *F* at the substations) corresponding to the selection registered on the code relays.

Figure 7. In the present case, code relays 1*C*, 2*C*, 6*C*, and 7*C* are operated. The group selection circuit (controlled by the C relays operated during the first five pulses) is prepared after the eighth pulse by the operation of relay 8*B*. Since 1*C* and 2*C* are energized, relay

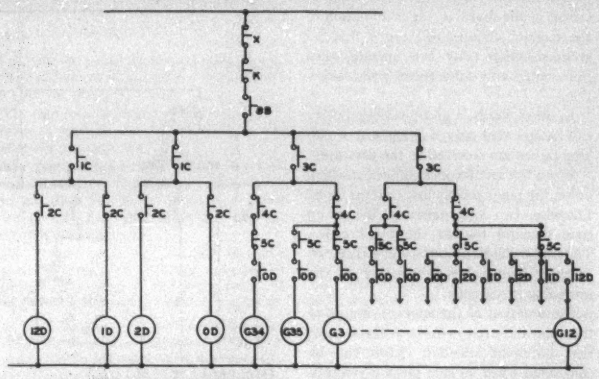

Figure 7. Group selection circuit employed to distinguish the group of a code

12*D* is operated. Also, since 3*C*, 4*C*, and 5*C* are not energized, the operation of relay 12*D* picks up relay *G*12.

Figure 8. After the end of the tenth pulse and the operation of relay *J*, a circuit is prepared for the operation of the point selection circuits (controlled by the *C* relays operated during the last five pulses. Since 6*C* and 7*C* are energized, relay 67*E* picks up. The operation of relays *J*, 67*E*, and *G*12 complete the circuit for *F*12–67 since 8*C*, 9*C*, and 10*C* are de-energized. As *F*12–67 operates, it extends its operating circuit to relay *K*, which also picks up and closes a locking circuit for itself and *F*12–67. Relay *K* opens the energizing circuit for the point selection relays so no more of them can operate and also drops the counting and code relays as well as relays *J* and *S*. They are thus restored to their normal position. Relay 10*B*, as it operated at the end of the tenth pulse, opened the circuit of relays *Y* and 12, which in releasing drop relay 67. High resistance relay *A* (see figure 2) picks up and holds the selection until the key is restored to its normal position.

At this stage, the office has completed the selection of a point and is ready to receive a check code from the substation. At the substation, since no check is required on the selection, a check showing that something was received is desirable where a carrier-current channel is employed.

Circuit Design Eliminates Possibility of Wrong Selection

Before continuing with the operation of the equipment, the group and point selection circuit safeguards against a wrong selection will be amplified.

The circuit for relay *J* is completed only if relay 10*A* has been operated in response to ten pulses on the line. If less than ten pulses are sent, relay *D* will release after the pulsing ceases, but relay 10*A* will not be operated. No new holding circuit is established for the counting and long-pulse register relays, and they release immediately without attempting a selection.

If more than ten pulses are received, the eleventh pulse will operate the lock-out relay *X*, which locks up until the set is released. Relay *X* opens the locking circuit of the long-pulse register relays, causing them to drop out and also stop the transmitting of impulses. No selection can then be made until the equipment is released.

Relay *J*, which can only operate if ten pulses (no more and no less) are received, closed the point-selection circuits. A point-selection relay can be operated only if four long pulses have been received and properly registered on four of the register relays 1*C* and 10*C*.

Inasmuch as the group code contains either one or two long pulses in the first five, either one or two of the *C* register relays 1*C* to 5*C* must be operated. If there is no long pulse in the first five, none of the relays 1*C* to 5*C* is picked up, and no group-selection relay (*G*1 to *G*45) can operate. Consequently, no point selection can be made. If only one long pulse is received in the first five pulses, one of the relays 1*C* to 5*C* will be closed. As relay 8*B* operates, one of the group selection relays *G*1 to *G*5 will close. Should two long pulses be received in the first five, two of the 1*C* to 5*C* relays will be energized, resulting in closing one of the group-selection relays *G*12 to *G*45.

If three or more long pulses are re-

ceived in the first five, an examination of the contact circuits will prove that no group-selection relay can operate, thus preventing any subsequent point selection.

In other words, a group-selection relay can be operated only if either one or two long pulses are received in the first five.

When the group codes contain one long pulse, the point codes must contain three. Likewise, two long pulses in the group code demand two in the point codes. Thus, the point codes contain either two or three long pulses, depending on the preceding group code.

Examination of the contact circuits of the point-code relays 6*C* to 10*C* will show that no point selection circuit can be completed when no long pulse is received in the last five pulses. The same is true when only one long pulse is among the last five.

When two long pulses in the last five are received, ten point-selection circuits are prepared which lead only to those group-selection relays associated with two long-pulse group codes. Therefore, a point selection can be made only if two long-pulse group-selection and two long pulse point-selection pulses are properly received.

If three long pulses are received in the last five, ten other point-selection circuits are prepared, leading only to those group-selection relays which are associated with the one long-pulse group codes. Therefore, a point-selection relay can be operated in this case only if one long-pulse group and three long-pulse point-selection pulses are properly received.

Should four or more long pulses be in the last five, the contacts of relays 5*C* to 10*C* cannot close a point-selection relay circuit.

Summing up, it is clear that a point-selection relay can be operated only if:

(*a*) Relay *J* is operated in response to at least and not more than ten total pulses.

(*b*) One group-code and three point-code relays are operated.

or

(*c*) Two group-code and two point-code relays are operated.

(*d*) At least and not more than four long pulses are received.

All other combination of pulses will not complete a selection.

Substation Check

While no check is necessary on the accuracy of the selection at the substation, the use of carrier current as a channel makes it advisable to get some sort of a signal back to show that the carrier equipment is working. To do this, two pulses are returned which, at the same time, indicates the present position of the breaker or device to be operated. If, at that time, the device is closed, a long and short pulse code is sent to the office. If the device is in the open position, a short and long pulse code is transmitted.

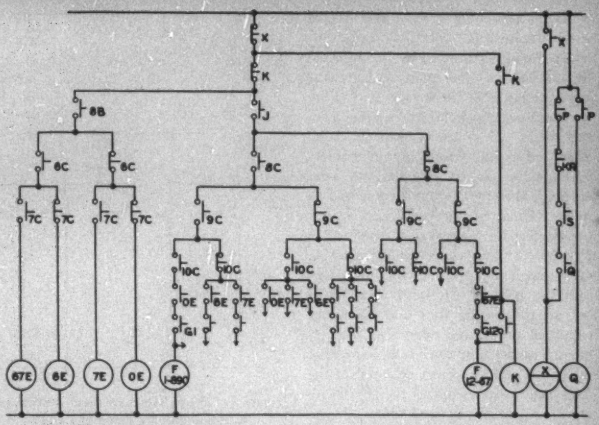

Figure 8. Point selection means used to isolate the point individual to a code

The substation sending follows the same sequence as has been described at the office except that the keying relay is opened at the end of the second pulse. The counting and code relays are restored to normal. At the office the two pulses are received registering on 11*C* or 12*C* depending on whether the selected device is closed or open. A circuit is completed only if either the first or second pulse is long. If both are short or if both are long, the contacts of 11*C* and 12*C* keep the circuit open. The relay energized in response to this signal controls the red and green lamp relay. Should the selected device be closed, the first pulse is long (and not the second) and relay 11*C* is operated. The lamp relay is energized connecting the red lamp in the circuit. Relay 12*C*, which picks up when the first pulse is short and the second one long, causes the lamp relay to drop out, changing the lamp indication from red to green.

Operation Control

At the same time, connections are made to prepare the circuits for the transmission of the operation control codes. The point-selection lamp at the office is lighted only after the reception of a correct indication code from the substation. If, at this time, the selected device should automatically change its position, the new indication code is immediately transmitted to the office.

The dispatcher may now operate the master control key which sends through a three-pulse code, depending on the position of the twist key of the selected point. The codes used are a long-short-short combination for closing and a short-short-long combination for tripping. The relays thus operated have their locking circuit through the twist key providing an antipumping feature.

After the three pulses are transmitted, further transmission is stopped by relay 3*A*. At the substation, the circuit is set up only if three pulses are received and the first or third one long. The device then operates and the changing of its auxiliary switch sets up the sending circuit to initiate transmission of the new indication code. As the new code is received at the office, the lamp relay is controlled as previously described.

In order to insure that the lamp relay has properly changed, a check code is sent from the office to the substation. A single long pulse is sent if the lamp relay is energized while a single short pulse denotes the de-energized position of the lamp relays. When one of these types of pulses is received at the substation, relay 11*C* is operated if the red lamp is lit, but will not be under the green lamp condition. In either case, if the check code from the office agrees with the position of the selected device, no further action takes place. If they do not agree, a new indication code is transmitted.

The dispatcher may keep the selected point as long as desired and repeat the closing and tripping operations at will. Meanwhile, the device is constantly supervised, and any new position is automatically indicated at the office.

Releasing the Selected Point

When the dispatcher desires to release the selected point, he restores the point-selection key. If no pulses are being received at this time, restoring the point selecting key opens relay *A*. Relay *A* is arranged to send a single release pulse.

In order to make a last check of the lamps at the office against the actual position of the selected device, the release pulse is made long if the red lamp is lit and a short pulse for the green lamp. This action is the same as previously described except all equipment resets to normal if the signals agree.

All other stations which have locked out are also automatically unlocked by the reset pulse.

Automatic Operation From the Substation

When a device changes its position in the substation, the selecting code is sent to the office in the same way as during a selection with the exception of the check code. Here, both sets of signals originate at the substation, so the indication code of two pulses follows immediately after the ten-pulse selecting code as pulses eleven and twelve.

An audible alarm and flashing disagreement lamp informs the dispatcher of the change. The disagreement lamp is so named because the position of the control key and indicating lamps are not in agreement. Its chief function is to assist the operator quickly to locate the unit which has operated automatically in the remote station.

Should several devices change position simultaneously, they report to the dispatcher in sequence. The order of preference is settled by the code since a station locks out if it is receiving a long pulse while sending a short one. Also, within a station, the code with the first long pulse, where another code has a short one, will be sent through first.

Conclusion

The new self-checking system is particularly applicable to large multistation applications, especially where carrier current is used as the controlling channel.

The possible source of code mutilation may be summed up:

(*a*) One or more pulses are lost due to relay failures or line trouble. In this case, a selection cannot be made.

(*b*) One or more pulses are added due to relay failures or line trouble. Again, no selection can be made.

(*c*) Two or more short pulses may flow together to form a long pulse. This results in less than the correct number of pulses and also too many long pulses. Therefore, no selection results.

(*d*) A long pulse may be split into two short pulses. The selection cannot be completed because of too many pulses as well as an insufficient number of long pulses.

(*e*) Should the long-pulse indicating relay *P* fail to release on a long pulse, no selection results as too few long pulses are received.

(*f*) Also, if relay *P* should drop out on a short pulse, too many long pulses are received and no selection is possible.

Thus all reasonable possibilities of wrong selections are reliably prevented and no check-back is necessary.

Discussion

F. Von Voigtlander (Commonwealth and Southern Corporation, Jackson, Mich.): Increasing interest is being shown by operating companies in the application of supervisory control schemes to power systems, chiefly as a means of reducing operating costs and improving service.

In contemplating the application of supervisory control to a given power system the first consideration would be whether or not the control system was applicable. I would, therefore, like to ask the author what is the field of application of this control system?

If it was found that the installation of supervisory control could be justified on the given power system, the next question would be what does this system offer that is not available in other modern control systems?

An important consideration in the successful operation of automatic equipment is maintenance. Equipment may suffer not only from lack of maintenance, but from overzealous maintenance as well. Another question I would, therefore, like to ask is what form and extent of maintenance is required by this control system and is there any way in which the equipment would give warning of faulty maintenance before actual failure took place.

D. R. Pattison (nonmember; Pennsylvania Electric Company, Johnstown): We are large users of supervisory control equipment and have found this type of equipment very reliable provided it is not overmaintained. We are extremely interested in the general trend toward simplification and have always wondered why supervisory control systems outgrew the original audible type, which in our estimation is the simplest form of remote control.

It has been our belief that the operating companies should at all times keep their remote-control requirements along logical and practical lines and avoid frilly requirements which of necessity complicate the equipment.

The manufacturers have been very generous in this respect and have at all times attempted to meet the special requirements which in a large number of cases represent whims of individual engineers or operators.

It is felt that the self-checking system offers a simplification in that the back and forth checking operation is eliminated.

E. E. George (Tennessee Electric Power Company, Chattanooga): Operating experience with remote control of various kinds indicates that the author's proposal to eliminate the check back system is a step in the right direction.

To those who feel that the multiplicity of relays in extensive applications of supervisory control may involve operating delays due to testing and maintenance, is suggested that the methods of the communication companies be imitated. In dial switching systems a large group of relays are mounted on a base plate which has plug and jack connections so that the whole base with these relays can be instantly removed from the switchboard and replaced by a spare unit. The connector and selector switches used in the step-by-step dial system are good examples of this construction.

G. De Croce (nonmember; Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.): Replying to Mr. Von Voigtlander, this system differs from other systems in that it is applicable to large multistation applications because in these instances the selection time remains a constant and the over-all equipment is materially reduced.

The best known method of anticipating trouble is to make visual inspections of the equipment. This inspection enables the maintainer to determine the cleanliness of the equipment and permits an observation as to the regularity of operation of the operating relays.

Mr. Pattison raises a point which should be generally digested by the industry at large, that is, the elimination of overspecial features and requirements. If this thought is carried out it will generally make for a reduction in cost and a simpler equipment.

Present-day supervisory control equipments have outgrown the audible type because it is generally accepted that a continuous indication of the position of remotely disposed devices is far better than to have an operator dial for a supervision and depend entirely upon his hearing to determine the exact position of the device.

Mr. George's contribution to this paper indicates the confidence in this type of equipment by those operating companies who have had previous experience with supervisory control.

The reliability of this type of equipment and its freedom from maintenance service has been demonstrated by the number of successful installations now in operation. It is felt that in view of present field experience the need for a removable jack-type relay where the relays are grouped becomes unnecessary.

Transmission Features of the New Telephone Sets

By A. H. INGLIS
ASSOCIATE AIEE

Synopsis: The new telephone instruments now being introduced by the Bell System result in an outstanding improvement in transmission performance in service. The evidence for this, as obtained by comprehensive laboratory and field tests, is presented here, together with a discussion of the factors responsible for this superior performance and of the consideration involved in its appraisal.

NEW TELEPHONE instruments are being applied in the plant of the Bell System to the desk stand, wall set, and handset, and result in markedly improved transmission performance. The new instruments are associated with the antisidetone feature which is also applied to the older sets already in plant. The selection of these particular designs from the wide choice made possible by new design technique, materials, and manufacturing methods, has been based on developments in the methods for quantitatively rating the relative merits of different designs. In general, there has been consistent effort over a period of years, to base these ratings primarily on performance in service rather than on laboratory tests.

The factors influencing service performance are so many, and so complicated in their relationship, and are in so many cases difficult or even impossible for the designer to evaluate or control, that their net effect on performance cannot be predicted with certainty by laboratory methods. Of necessity, such methods involve a limited selection of primary test conditions, and an even more limited selection from the possible combination of these conditions. This is particularly true in the rating of the transmission performance of a telephone set. Laboratory tests are essential in the study and analysis of design problems, and are invaluable similarly in interpolating, supplementing, and explaining service performance results. In determining the reaction on the user of the transmission features of possible designs, however, the field performance test has been found of first importance in deciding what particular characteristics to include in the new telephone instruments and circuits.

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1. For all numbered references, see list at end of paper.

Important Transmission Characteristics of the New Telephone Sets

The specific transmission design features of the new instruments, are described elsewhere.[1] The purpose here, therefore, is to discuss primarily the outstanding improvements in performance resulting from the application of the new instruments and the antisidetone feature which has been available for some time.

These improvements are

1. Those due to the station circuit, which, as compared with the previous station circuit,

a. Largely reduce the efficiency of the sidetone path between transmitter and receiver, without materially affecting the electrical efficiency of the set in transmitting or receiving. This means that sounds, either noise or speech, which are picked up by the transmitter, are reproduced in the receiver of the same set at a much lower level.

b. Reduce the susceptiveness for certain types of party line sets to interference with reception by noise set up by power transmission systems.

2. Those due to the physical characteristics of the transmitter and receiver.

Several of these features have been available for some time, and have, of course, been introduced into the plant as they became available. The new transmitter and the antisidetone circuit, for example, have been standard for some years and have already been installed in large numbers.

Figure 1 shows both the new handset and the desk-stand forms of mounting, including all these features as integral parts of their design. The new desk-type transmitter and receiver can, of course, be used with wall sets.

The schematic drawing of figure 2 indicates the general arrangement of parts in the new station transmission circuit for either type of set.

In describing the results produced by these transmission features, and the methods employed in measuring and rating these results, it seems desirable to include some discussion of the characteristics of a telephone conversation as distinguished from a direct, face-to-face conversation, so that the various effects of the new circuits and instruments may be seen in as correct relative proportion and as generally comprehensible form as possible.

Some Elements of the Station Transmission Problem

In either a telephone or direct conversation, successful communication depends on the characteristics of the talker and of the listener, and their reactions to each other and to the character of their surroundings. In a direct conversation such, for example, as across a desk, the environment is in general the same for both talker and listener, and their ears are materially aided by their eyes. In a telephone conversation, however, not only may the surroundings of talker and listener be entirely different, but a third element, the telephone system, is added to the environment of each user, which complicates his reaction, not only to his own surroundings, but also to the other party to the conversation. Furthermore, for obvious economic reasons, the

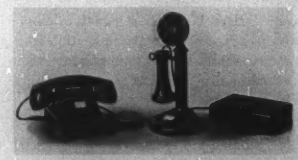

Figure 1. The new handset and desk-stand telephone instruments

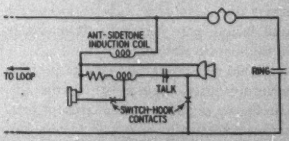

Figure 2. Schematic transmission circuit of antisidetone coil

natural binaural reception of direct conversation, with its advantages in discriminating between sounds from different directions, is replaced in the telephone conversation by a monaural medium.

Fundamental differences of this kind between telephone and direct conversation must be taken into account in the design of a telephone transmission system

if satisfactory results are to be obtained. For example, the talker is accustomed in a direct conversation to regulate his talking volume by what he himself hears under prevailing noise conditions (which incidentally are the same for the listener), by the ease with which he hears the other party, and by the ease with which the listener appears to hear him. By experience, under ordinary conditions, the first factor mentioned, the loudness with which the talker hears himself, probably comes to be the primary control on his talking volume.

These various factors also serve to regulate talking volumes in conversation by telephone, but their magnitudes and the relations between them differ from the condition of face-to-face air-path conversation and vary from one type of telephone connection to another. For example, the "sidetone" of the telephone set, being materially higher than the air-path sidetone, deceives the talker, not only by making him think he is talking louder than he really is, but also by apparently modifying the noise conditions under which he is talking in the pickup and amplification of room noise by his telephone transmitter. Since, in addition, the efficiency of the telephone circuit itself may be different in the two directions of transmission, the loudness heard by one party may differ more from that heard by the other than in the case of air transmission. Then, too, noise conditions may be and frequently are quite different at the two ends of the telephone circuit. Figure 3*A* shows the probability of noise of various average intensities at subscribers stations as determined by several surveys covering a large number of locations. On the assumption that any one of the stations represented by these data may with equal probability call any other one, figure 3*B* has been computed, showing the probability of noise at the two stations of a telephone connection differing by more than a certain amount. It will be noted that there is about an even chance of the noise at the two ends differing by more than 12 decibels. In view of these differences, a person's judgment of how well he is heard and understood cannot be as direct as in the case of air transmission.

In addition, the transmission over the commercial telephone system affects the quality of the received speech more than the usual room surroundings in air-path transmission. While acoustic resonance and reverberation in a room do distort speech, in the extreme case to a point where understanding may be difficult, uch a condition is distinctly unusual. Equal freedom from distortion in a telephone system is a more difficult and expensive condition to obtain than in direct conversation a few feet from a listener. Something less than perfect reproduction must suffice, for the present anyway, if costs are not to be prohibitive.

All of these differences involve the acquiring by the user of a set of telephone habits which differ from those he has acquired in direct conversation. The problem of the transmission design of a practical telephone system requires, then, for a satisfactory solution, not only a determination of the proper speech levels to be delivered, and of the sidetone characteristics which will, under the conditions of a telephone conversation, give optimum results with the noise encountered, but also a decision as to what particular frequency range and characteristic to choose. Properly designed, a telephone transmission system should minimize, to the degree consistent with costs, its inherent differences from direct conversation, and make it easy for the ordinary user to get, without undue effort, results which are satisfactory to him in comparison with direct conversation.

In the earlier days of telephony, the problem presented appeared much simpler. It was, in effect, unidimensional, calling primarily for more efficient instruments and circuits; more and more power delivered to the listener's ear. While methods for the control of sidetone were not unknown, the importance of such control was not fully appreciated. Little choice was available in the quality of reproduction provided by transmitter and receiver, because of meager design knowledge.

Relatively recent and quite rapid developments in knowledge of the problems involved, in materials, methods, and measuring facilities, have now presented the necessity for a solution in essentially a three-dimensional form. These three dimensions may be described as volume, noise, and quality. The solution of the problem on this basis is obviously more difficult, and has required the development of methods for quantitatively evaluating and rating their characteristics in terms of some common yardstick.

Methods of Rating Transmission

For reasons already suggested, such a yardstick must be based on service performance—on the results obtained by actual users in the course of day-to-day telephone service.

Extensive investigation has indicated that the best comparative measure of this

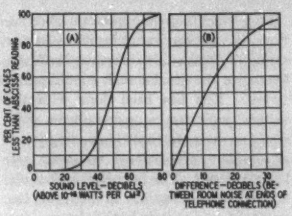

Figure 3. Noise conditions at telephone stations

transmission performance in local exchange service is to be found in the time rate of the occurrence of repetitions required by subscribers for understanding telephone conversations.[2] Or, more explicitly, when two transmission conditions have the same repetition rates, all other service factors being equal, these conditions are taken to be equal with respect to transmission performance. Where two conditions are not alike it is usually possible to evaluate the difference in the repetition rates for the same users by inserting distortionless loss in the better condition until both have equal repetition rates.

Thus, by taking as a reference, a typical telephone circuit of specified make-up, the effects of various factors such as distortion, noise, attenuation, sidetone, or type of instrument, may all be expressed in the common terms of the reference circuit trunk which will give the same repetition rate.

Instead of making this adjustment in every case for the purpose of evaluating the relative performance of different test conditions for the same users, the evaluation may be made rather closely over a limited range by the following typical relation derived from repetition observations on circuits containing trunks, the losses of which were varied over a range of values.

$$db = 50 \log_{10} R_1/R_2 \text{ (see reference 3)}$$

where R_1 and R_2 are the repetition rates of two conditions under comparison, and the *db* figure is the change in the reference trunk which has the same relative effect on the repetition rate.

Such a method is, of course, somewhat cumbersome, and requires a large amount of data to iron out random variations and individual peculiarities of little general interest. But as the fundamental rating method, supplemented by laboratory test, it has been systematically used in studying the value of the antisidetone circuit and in selecting instrument characteristics.

Supplementing the repetition observations, it has been found useful in service rating to obtain data on speech levels delivered to the line for each condition observed. This has been done with the volume indicator, a vacuum-tube voltmeter so designed that the reading is approximately proportional to mean syllabic voltage.[4] The information thus obtained is useful not only in analyzing the results of service tests but in determining typical values for speech levels, necessary for laboratory tests.

Laboratory tests are of two general types, objective measurements and subjective tests. Transmission measurements cover a wide field with objectives ranging from the physical analysis and study of different designs, to the determination of over-all performance characteristics of structures and systems. It is these latter tests that we are more particularly interested in here, as most descriptive of the physical properties of importance in providing telephone transmission service.

Subjective tests in the laboratory may be said to be midway between physical measurements and field performance tests. Made under controlled and somewhat artificial conditions, they indicate quantitatively the capabilities of a telephone system in transmitting articulate speech under the particular conditions of the test. They cannot, of course, indicate the relative probability of occurrence, and hence importance, of these different conditions, nor predetermine how well the subscriber will avail himself of the capabilities provided.

Consideration of some of the results of investigations in both laboratory and field will do much to explain the rather large transmission improvement realized by the introduction of the new sets in actual service, particularly if examined with the conditions of a direct conversation as a basis of comparison.

The Station Circuit

There are two characteristics of the new station circuit of particular importance from a transmission standpoint.

Reduction of Sidetone

The first is the antisidetone induction coil through which the transmitter and receiver are coupled to the line. This coil comprises, in addition to three transformer windings, a balancing network. The circuit, made up of the four elements, transmitter, receiver, line, and network, coupled by the transformer, functions in such a manner that the transmitter and receiver are in conjugate relationship, that is, voltages produced by the transmitter are balanced out and do not affect the receiver. Theoretically, such a circuit, with pure resistance elements, can be perfectly balanced at all frequencies with complete elimination of sidetone, and at the same time be as efficient as can any transformer coupling in an invariable telephone set,[5] for the transfer of power from the transmitter to the line, and from the line to the receiver.

This type of circuit is not new in principle, and many varieties are known and have been described.[6] Many of these arrangements, for one reason or another, are not suitable for application. Some, for example, call for impedances of transmitters or receivers differing widely from those available. Certain others are not economical for common battery service, where the transmitter must receive its battery supply from the line. Still others require relatively complicated and expensive cording and switchhook arrangements. The circuit which has been chosen for general common battery subscriber station application, and shown schematically in figure 2, is not only as simple and as easily adapted to Bell System conditions as any, but permits a coil design which is economical to manufacture as well as efficient in performance. Other types of antisidetone circuit have been adopted for local battery station service and for operators' telephone sets.

The theory of operation of this antisidetone circuit has already been discussed elsewhere.[7] It is intended here to show the general purpose of the application, some of the considerations involved in the design, and the kind of results accomplished.

While in theory, complete elimination of sidetone is possible, as well as ideal efficiency of transformation, in practice, neither objective can be entirely realized. The unavoidably wide variations in line impedance looking from the set, ranging from high positive to high negative phase angle, and from a few hundred to more than a thousand ohms in magnitude, together with other practical departures from ideal conditions, necessitate a choice between a high degree of sidetone balance, and the standardization of a minimum number of coil designs. The variations in loop length and resistance, by their effect on transmitter battery supply, and consequently on transmitter resistance, furthermore cause variations in the absolute transmitting and sidetone efficiency of the terminal set, which must be taken into account in the station circuit design.

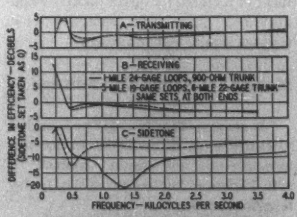

Figure 4. Circuit efficiency of antisidetone circuit versus sidetone circuit

The actual design chosen is so arranged as to favor sidetone balance on average and shorter loop conditions where transmitter battery supply is greater, with consequent higher sidetone, and to favor transmitting and receiving efficiency on longer loops where battery supply is low. Since loop losses are greater for transmitting than for receiving because of transmitter battery supply loss, the ratio of the transformer is such as to favor the transmitting efficiency of the set somewhat in comparison to the receiving efficiency. This has the advantage of raising the transmitted speech level further above line noise. The same idea, of course, was followed in the design of the sidetone set.

The resultant antisidetone circuit adopted and here discussed, as compared with the sidetone circuit previously in general use, when equipped with the same transmitter and receiver and on the same loop and trunk, reduces sidetone on the average by about ten decibels. Under the most unfavorable conditions of use, the reduction is unlikely to be less than about seven decibels compared with the corresponding sidetone connection. Under the best conditions of balance encountered the reduction may be as much as 12 decibels. On the effective basis of transmission the average net improvement in transmission which results is about six decibels.

From the electrical circuit standpoint alone, the efficiency of the antisidetone arrangement is below that of the sidetone set in the order of about one or two decibels in transmitting and in receiving, which is necessitated by the limitations of practical design and circuit conditions discussed above.

Figures 4*a* and 4*b* show for transmitting and receiving, respectively, the difference in efficiency, with respect to frequency, of the antisidetone set from the sidetone set, each with the same instruments. Two subscriber loop and trunk conditions are shown, an average loop and trunk, and a long cable connection.

Figure 4*c* shows the variation in sidetone reduction with frequency, of the new set as compared with the corresponding standard sidetone set, for the same two circuit conditions as above. The curves are indicative of the effect of variation of circuit impedance on sidetone balance, in changing not only the magnitude, but the frequency range in which the best balance occurs.

Data of this sort alone do not, of course, indicate the relative transmission performance of the two sets. The beneficial effect on the telephone user of the large reduction in sidetone must be evaluated on the same yardstick as the losses in transmitting and receiving efficiencies which, in the practical case, accompany this reduction in sidetone. McKown and Emling have shown the effect of changes of this sort on the results obtained by the ordinary telephone user, in terms of net effective transmitting and receiving loss, as determined by service observations.[3] Their data, shown in figure 5, are relative to the sidetone of a reference set. The heavy solid lines are the original experimental data, the dotted extensions to these curves being extrapolated.

In addition to the original ordinates, others are shown which are of interest. They are based on the results of loudness balance tests, and while not perhaps of great precision, do approximately indicate the relationship of the sidetone of a telephone conversation to that for direct speech, and illustrate the differences in the effects of sidetone for transmitting and for receiving.

On each curve are indicated the average sidetone value of the standard sidetone and the new antisidetone set, each, as before, with the new transmitter and receiver. There is also shown the range of sidetone for each type of set, within which practically all service conditions will fall. This indicated range takes into account not only variations in sidetone balance due to line impedance variations, but changes (with loop resistance) in battery supply to the transmitter. It should be noted that in only a few cases is the absolute sidetone of the antisidetone set on the worst sidetone conditions, as high as or higher than that of the sidetone set on the best sidetone conditions, and then only by a small amount. Furthermore, in spite of the wider variations in sidetone of the antisidetone set, these variations are over a range such that the resultant variations in effective losses are smaller than for the sidetone set.

Considering figure 5*a*, it will be noted that for either sidetone or antisidetone sets, the sidetone is louder than for natural speech sidetone, which, as noted before, makes the user think he is talking louder than he actually is. The average sidetone reduction of ten decibels for the antisidetone set results in less of this restraint on his talking level, with a resultant net effective gain in transmitting of about four decibels compared with the sidetone set.

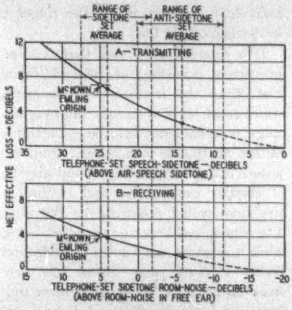

Figure 5. Effects of sidetone on user of telephone

In receiving, figure 5*b* sidetone introduces an effective loss by the reproduction in the telephone ear of room noise picked up by the transmitter. It will be noted that for the antisidetone set, the reproduced noise is in general appreciably lower than the room noise itself. Inasmuch as room noise also interferes directly with received speech in the telephone ear by leakage under the receiver cap, the contribution to the total noise of the sidetone pickup of the antisidetone set is in most cases small. This is not true for the sidetone set, where in many cases the sidetone noise may constitute the principal interfering noise. The resultant net effective gain in receiving is about two decibels compared with the sidetone set.

This is a good illustration of the type of information which can be obtained only from a field study. For example, the relationships indicated on figure 5 are dependent on how far away from the mouthpiece of the transmitter and at what level the speaker talks, and on how tightly to his ear he holds the receiver. These in turn are resultants of all the conditions of the particular telephone conversation. If incoming levels are so high as to be uncomfortable, the receiver may well be held farther away from the ear. In that event, of course, the sidetone conditions of the set become relatively less controlling. The weight, size, and shape of the instrument in his hands may similarly affect the subscriber's use of it, the results he gets, and the relative importance of various factors of telephone design.

For such reasons, not only must laboratory performance tests be supplementary and subsidiary to field tests, but additional field tests must be the basis for determining the effect of any major changes in design, whether or not those changes are electrical, acoustical, or purely mechanical.

Considerations of this sort emphasize the importance of having clearly and explicitly in mind the conditions and relationships of direct conversation, as a general reference for the interpretation and explanation of the effects of telephone design on telephone conversations. The sidetone ordinates of figure 5, for example, not only suggest the difference in function of the antisidetone circuit in transmitting and receiving, but also emphasize the fact that the over-all sidetone resulting from the combination of circuit, instruments, and method of use, is the important factor rather than the sidetone circuit efficiency only. Such matters are easily lost sight of, if design is not properly co-ordinated in its correct perspective.

The reduction of sidetone provided by the antisidetone sets is of further advantage in two rather different ways.

In attaching a transmitter (which is an amplifier) and a receiver, to a common handle which mechanically couples the two, a condition is set up in which the gain under certain conditions may exceed the loss in the path made up of handle, air, and electrical sidetone circuit. Sustained oscillation, or howling, will then result between transmitter and receiver. Even if this point is not reached, but is approached within six decibels or so, impairment of quality results from incipient oscillation. The greater sidetone circuit loss of the antisidetone circuit provides an additional margin of safety against any such condition.

The granular carbon of the transmitter, and the design of the transmitter itself must be carefully controlled, or serious noise—transmitter "burning"—will cause noise in the receiver of the set. The mechanical and electrical wear and tear of service tends to make this transmitter noise worse. In the new transmitters this "burning" has been kept at a low inherent value throughout life. The antisidetone circuit, however, provides a margin of safety against the small amount remaining, so that with this set there is

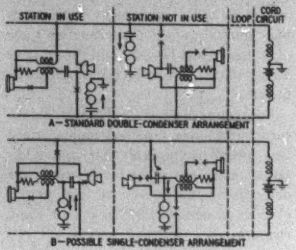

Figure 6. Ringing arrangements for party-line service

less likelihood of transmitter noise causing impairment of reception.

Reduced Susceptiveness to Interference

It will be noted from the schematic circuit drawing figure 2 that two condensers are used in the new sets, one in the antisidetone transmission circuit, and a separate one with the ringer. In some types of party-line practice, the ringer of the set is connected for some parties from one side of the line, and for the others from the other side to ground.

Figure 6 shows schematically two such ringing arrangements during the conditions of conversation, 6*a* as used in the new sets, and 6*b* with one condenser common to transmission and ringing circuits. It will be noted that in the standard circuit adopted (figure 6*a*), if any longitudinal noise voltages exist between the central office and station grounds, there is an equal voltage drop from each side of the line to ground through the ringing paths (assuming the two ringer condenser paths to be identical). The voltage drop across the terminals of the talking set is therefore zero and no noise results.

If the arrangement of figure 6*b*, corresponding closely to previous designs, were used, however, this condition would not obtain. The condenser of the station in use being common to the transmission circuit as well as the ringing circuit, the noise voltage drop across this condenser is introduced in the transmission circuit. In addition there are other paths to ground from each side of the line through the transmission circuit which are not of equal impedance. The net result is a residual noise current through the receiver of the talking circuit.

In the actual case, the impedance of all ringers and condensers is not identical and there are often more parties connected to one side of the line than the other. Even under these relatively unfavorable conditions, however, the two-condenser arrangement adopted reduces the susceptiveness of the set to interfering noise by as much as 15 decibels. A further material reduction is realized by the high impedance of the ringer used in the new sets, so that in most cases interfering noise at grounded ringer stations will not differ materially from that at individual stations where the ringer is bridged across the line.

It is interesting to note that this improvement is realized at little additional cost, since the transmission condenser, which must be of relatively high capacitance, is permanently bridged by the transmitter, so that it is protected from exposure to any large voltages, and may be of cheaper construction and smaller in size than would otherwise be the case. The ringing condenser on the other hand, while it must be constructed to withstand higher voltages, may be of relatively small capacitance, which gives more uniform and better ringing and dialing performance.

Characteristics of Transmitter and Receiver

Since the individual design characteristics of the new transmitter and receiver are discussed elsewhere,[1] attention here will be centered on the over-all effects of these characteristics in the complete transmission system, as indicated both by laboratory and by field test. As stated before, the problem may be more or less arbitrarily separated into three correlated problems—volume, quality, and noise.

As in the case of sidetone, these problems appear, perhaps, more nearly in a proper perspective, if considered in comparison with the corresponding factors in a direct conversation. It must be remembered that telephone service does not consist in the provision of a mechanism, per se, but in the provision of facilities for conversation, to which the mechanism should be incidental, however important. Since the inherent conditions of such a conversation are quite different in many respects from those of a direct conversation with which, consciously or unconsciously, it will be compared in its over-all results, the parallelism in detail should not be too exact. Departures from the conditions of direct conversation in certain respects which are relatively unavoidable, may be best compensated for by deliberate departure in certain other respects. For example, the physical absence of one party to the telephone conversation, and the monaural nature of such a conversation, may be partially compensated for by delivering to the ear of the listener a somewhat higher speech level than he is accustomed to in direct conversation. The limitation of frequency band width imposed on the telephone medium, largely for economic reasons, may be minimized in its effects if the transmission characteristics in the available band are other than a facsimile of the corresponding band in direct conversation. All such measures must be employed with knowledge of their effect on the ultimate objective, that the telephone conversation may be easy and natural.

General Requirements

It is easily seen that for any particular over-all frequency characteristic of a telephone transmission system, there are practically an infinite number of ways in which it can be split up between transmitting and receiving characteristics. From this standpoint alone, then, there is no particular "best" transmitter or receiver frequency response. From other standpoints, however, certain general types of individual characteristics, both in frequency and efficiency, are to be preferred to others, particularly when considered in their practical application to an already existing telephone system. It has been pointed out[9] that, in general, development has been toward a telephone system where both transmitter and receiver are relatively uniform in their frequency characteristics. Induced noise appears to be so evenly distributed with frequency that such response would not appear to magnify the interference problem.

Transmitting efficiency should be as high as required to keep the speech well above induced noise but not so high as to cause excessive crosstalk into other telephone circuits. The maximum desirable received level is determined for a given telephone system by the limitations of the human ear in accepting with comfort speech levels above a certain intensity. Finally, the practical necessity of working as satisfactorily as possible in conjunction with the telephone transmitters, receivers, and sets in the existing plant during the period of transition, places a practical limitation on the amount of change that is desirable in relative levels of either transmitting or receiving.

With regard to frequency range, previous work[10] indicated the desirability of designing circuits to transmit frequencies from 200 or 300 cycles up to about 3,000 cycles. Gains in articulation and naturalness are realized by increases in this band width, but are progressively smaller for successive equal increments in fre-

quency. A 3,000-cycle band properly used gives good transmission both in articulation and naturalness, but frequency limitation is essentially an economic one, subject to change as conditions change. Recent work on the new multiple-channel carrier systems has indicated justification in these systems for providing a somewhat wider band, from about 150 to about 3,500 cycles.[11]

Over-all Frequency Response

In describing the frequency characteristic of a transmission system it has become customary to refer to it as more or less "flat," where "flat" is assumed to be synonymous with "perfect" as far as the relative transmission of various frequencies is concerned. In measurements of the elements of an electrical circuit, from which this terminology came, the word is useful since, when the measurements are properly made, at any rate, the basis of comparison implied by the word "flat" is generally understood. This is also true, although probably to a more limited extent than is generally realized, when the term is applied to electroacoustic transmission systems, where free progressive, plane air waves of various frequencies are transferred to an electrical system, or vice versa, by means of microphones or loud speakers.

In the case of a telephone system, however, where a transmitter is placed close to the lips, and a receiver directly to one ear, and where the air waves are not free progressive or plane, use of the word "flat" implies a basis of comparison which is not self-evident. Much effort has been given recently to establishing an appropriate reference system, sufficiently simple in concept and ease of specification, to be useful in this connection. The result of this work has been a reference telephone system which, when spoken into, would give the listener in all respects essentially the identical sensation he receives in one ear when facing the speaker directly, with an air path one meter long between the speaker's mouth and the listener's ear, in surroundings without reverberation or noise. Such a reference transmission system has tentatively been called an "orthotelephonic" system.

The point of interest here is that when measured by any suitable objective method, the frequency characteristic of this "orthotelephonic" telephone reference system is not "flat" by a considerable amount in the ordinarily accepted usage of the term. This departure from "flatness" is caused by such factors as the frequency directive characteristic of the mouth, cavity resonance of the ear, and disturbance of the sound field by the head. The individual contribution of some of these factors is not as yet definitely determined.

Furthermore, for reasons mentioned, it is not self-evident that a practical telephone system of limited frequency range, should be "flat" with respect to the corresponding frequency band in this more or less basic orthotelephonic system which is not limited in frequency range. Having decided on the band width that is desirable and justifiable, it must still be determined, therefore, what particular frequency characteristics are preferable in this band.

In selecting from the many possible choices, the particular frequency response that seems best, several factors must be taken into account. This has been done by a study (under the conditions of actual service) of the relative results of several different experimental instrument designs, varying in frequency characteristics. The over-all frequency characteristics of the resultant choice are indicated for two typical circuit conditions in figure 7. These measurements were made with the artificial mouth and ear[12] and are plotted with reference to corresponding measurements on an orthotelephonic reference telephone system. For comparison the results of similar tests of the earlier Bell System handset[13] are shown also.

In considering these over-all telephone-system frequency-response characteristics in the light of previous discussion, there are several points of interest:

1. The large increase in response at both higher and lower frequencies with respect to the older handset, which in itself was a notable advance in this respect over previous types. This increase amounts to ten decibels or more from about 200 to 500 cycles and from about 1,700 to 3,000 cycles. This wider frequency range gives better naturalness of reproduction.

2. The type of the response. The general uniformity and absence of any marked resonance or irregularity is obvious. For either average or long loops the entire band from about 300 to over 3,000 cycles lies within a range of 15 decibels. It will be noted, however, that, for the average condition, the response at the higher frequencies (1,500–3,000 cycles) is distinctly above that for the frequencies below 1,500 cycles. This characteristic aids materially in the understanding of the low-intensity consonant sounds. The response on the longer loops would undoubtedly be correspondingly better if the high frequencies were raised so that the over-all characteristic more nearly resembled that for the average condition shown. It should be remembered, however, that for a standard set, to be used on all loop conditions, a response designed solely for the long loop, with its large loss at high frequencies, would be distinctly "tinny" and disagreeable in quality on average or short loops.

3. The materially smaller losses in the transmitted band for the average telephone connection than for the orthotelephonic system. Even for the long loop conditions the losses are no greater than for this orthotelephonic system up to about 2,200 cycles. In other words, for a large majority of telephone calls the received speech level will be higher for the same talking level than in the case of direct conversation at one meter distance. The desirability of this in a monaural system of limited frequency range has already been indicated.

Combined Effects of Circuit and Instruments

The part played by the antisidetone circuit in permitting better utilization by the subscriber of the capabilities of the telephone system, in increasing the level of received speech, and minimizing the effect of noise is summarized by the illustrative power level diagrams in figure 8, using typical values of room and line noise and other conditions.

The data shown were obtained by objective measurements with the artificial mouth, sound level meter, volume indicator, and artificial ear. Frequency weightings appropriate to the levels involved were employed in the sound level measurements.

Figure 8*a* shows, for the antisidetone set, the losses between the talker and listener under average room noise and circuit conditions. Figure 8*b* gives corresponding information for the sidetone set. For comparison, an approximate level diagram is shown also for direct speech. The relative speech levels at the transmitter for the two telephone conditions were adjusted to give volume indicator readings on the line in accordance with the results of service observations. The upper curves in each drawing

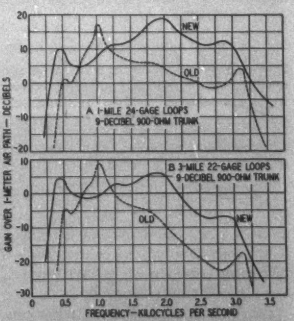

Figure 7. Over-all orthotelephonic frequency response of typical telephone connections

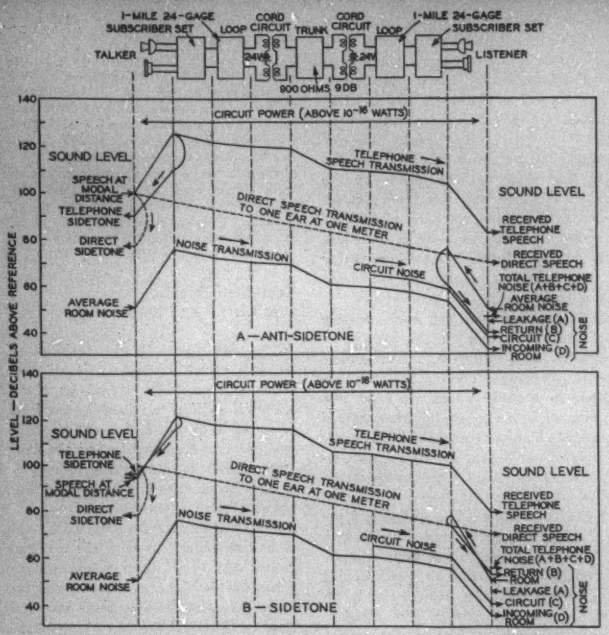

Figure 8. Power-level diagrams of typical telephone connections

are for speech and the lower for noise picked up by the transmitters.

At the transmitting end, the lower sidetone of the antisidetone set results in higher talking levels, with about four decibels higher speech level at the input to the circuit. In the over-all circuit, this gain is increased by the receiving end effect of the antisidetone circuit in minimizing the effect of room noise.

The total noise in the telephone ear, as shown on the drawing, has as its principal contributing factors,

1. Leakage of noise under the receiver cap.
2. Noise picked up by the transmitter and returned via the sidetone path and receiver to the listener's ear—termed "return noise."
3. Circuit noise.
4. Room noise picked up at the far end and transmitted over the circuit.

The different relative contribution of the "return noise" for the two sets is of interest. The net result is a total noise in the telephone ear, lower than the actual room noise for the antisidetone set, and higher for the sidetone set.

For the circuit and room noise conditions shown, the ratio between received speech level and noise is about 25 decibels for the sidetone condition, and 35 decibels for the antisidetone. The corresponding ratio for air transmission to one ear under the conditions shown is the order of 20 decibels.

Results of Laboratory and Field Performance Tests

It has been seen that the new sets are superior in volume and in minimizing the disturbances of noise. The frequency measurements just discussed have indicated marked superiority also in the quality of reproduction.

One measure of the effect of this reduced distortion is by means of the articulation test. Such tests have shown that for a typical telephone system equipped with the new telephone sets, 95 per cent of the letter sounds spoken into the transmitter are correctly understood by the listener. With air transmission, 98 or 99 per cent of letter sounds are correctly understood. The difference is almost entirely due to the broader frequency band transmitted by the air path.

With the final designs of the new sets, tests have been made by the methods developed for determining "effective" transmission.[2] The results of these tests have shown that the new sets under the conditions of actual service provide a marked advance in transmission performance. The average total transmitting and receiving gain is about 15 decibels on the effective basis of transmission, as compared to sets of the sidetone type used with the older type of instruments.[13]

Conclusion

In general, it appears that the notable transmission improvement which has been achieved in the design of the new telephone sets, in their freedom from distortion, higher effective volume, lower sidetone, and general convenience in use, makes possible a closer approach to the ease of a direct conversation than has hitherto been possible commercially.

Undoubtedly, further improvements in station transmission performance will, as in the past, be forthcoming with advances in the technique of design and manufacture, and in further knowledge of the requirements of the problem.

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Industrial Notes

Power Requirements in Various Industries.—Electroprocess operations consume more than one-tenth as much electric energy as the total amount generated for public use in the United States, the Federal Power Commission estimates in its report, recently released, on power requirements in electrochemical, electrometallurgical and allied industries. Past requirements are estimated at 13,324,000,000 kilowatt hours annually. Future requirements, probably within five years, based on trends and increasing demands in these industries, are estimated at 17,781,000,000 kilowatt hours per year, an increase of approximately one-third. The largest users in this group were aluminum and copper producers. Power used in the annual production of aluminum amounted to 2,597,000,000 kilowatt hours; for copper, 2,600,000,000. The complete report, containing numerous maps, charts and tables will be sold at $1.00 per copy by the Federal Power Commission, Washington, D. C.

Electric Iron Sales Show Gain.—The second order for 25,000 electric irons, duplicating the original 25,000 order within five weeks, presented convincing indications of an upswing in the business curve to the Westinghouse Electric & Mfg. Co. This order was received from the Consolidated Edison Company of New York City and will be used in its current appliance package merchandising campaign. Opened officially September 1, the merchandising campaign met with such an enthusiastic response in sales that officials of the Consolidated Edison Company found their original iron order would soon be exhausted. It is their opinion now that this second order may not be sufficient and if the public reaction continues as it did during the first few days of the campaign it is entirely possible that one or two more sizable orders may be necessary. Presumably reorders will be necessary also on the other "package" items offered to the public, including a radio receiver, toaster and lamp.

Boulder Dam Adds Another Line.—The General Cable Corp., New York City, has received from the Bureau of Power and Light, City of Los Angeles, a contract for manufacturing the third Boulder Dam transmission line. The new line will require over 6,000,000 pounds of copper and will be the same as the original installation—General Cable type HH hollow copper conductor, 1.4 inches in diameter, to be operated at 287,000 volts.

Large Magnet Castings.—Eighty tons of castings have recently been completed for use in the huge cyclotron magnet which Ohio State University plans to use in the study of nuclear physics, and particularly in the disintegration of atomic nuclei and in the production of artificial radioactivity. These large castings have been made by The American Rolling Mill Co., Middletown, O., from iron of very low impurities similar in analyses and properties to ARMCO ingot iron.

Sodium Lighting in Liberty Tunnel.—The remodeled mile-long Liberty tunnel in Pittsburgh will be lighted by a sodium safety lighting system employing 243 luminaires developed by the General Electric Co. The orange-yellow light from special enclosed-type units employing 10,000-lumen lamps will provide the illumination of the heavily travelled tube. Supplementary Mazda lighting will be used at the tunnel entrances for daytime burning only, and to compensate for the quick change from daylight to the monochromatic light of the sodium safety lamp. The Liberty tunnel will be the largest in the country to utilize the sodium lighting.

American Lava Acquires Ceramic Company.—The American Lava Corp., Chattanooga, Tenn., has acquired all equipment and good will of the American Ceramics & Specialties Corp., Jackson, Mich., and will remove the equipment to its laboratory and works at Chattanooga. Carl R. Hower, vice-president and manager, and O. D. Riseden, production engineer, will be retained in sales and engineering capacities with the American Lava Corp.

Allis-Chalmers Moves Dallas Branch.—The Dallas, Texas, district office of the Allis-Chalmers Manufacturing Co., has been moved to a new location, 1800 N. Market St., where the power, electrical and industrial divisions of the company now occupy an entire building. This 3-story building houses not only the company's offices, but also its warehouse, which carries an extensive stock of Texrope belts and sheaves, transformers, motors, starters and pumps. It also has a small machine shop where minor repairs may be made.

Trade Literature

Relays.—Bulletin GEA 2961, 16 pp. Describes a-c and d-c relays, type GTR, applicable for control, regulating or protective service; operated by solenoids or electromagnets. General Electric Co., Schenectady, N. Y.

Bearing Bronze.—Bulletin. Describes a new development in bearing materials—LEDALOYL, a self-lubricating bearing bronze, combining lead, graphite and oil in the alloy. Johnson Bronze Co., New Castle, Pa.

Condensers.—Catalog. Describes standard items of an extensive condenser line, including the most popular type of carbon and wire-wound resistors. Features are three pages of exact-duplicate replacement condenser listings and two pages of exact-duplicate motor-starting capacitor replacements. Aerovox Corp., 70 Washington St., Brooklyn, N. Y.

Photometer.—Bulletin, 4 pp. Describes a new photoelectric light meter for measuring illumination, testing automobile headlights, determining photographic exposure, etc. Intercontinental Marketing Corp., 8 W. 40th St., New York City.

Relays.—Bulletin, 10 pp. Describes relays of various types, including circuit control, electronic, time delay, transmitter, break-in, telephone extension, overload, etc. Price list is included. Advance Electric Co., 1260 W. 2nd St., Los Angeles, Calif.

Gear Motors.—Bulletin GEA 1437C, 12 pp. Describes integral and fractional horsepower gear motors for slow speed operation. Output shaft speeds 600 to 6 rpm; motors 1800 rpm, single phase, polyphase and direct current; $\frac{1}{8}$ to 75 hp. General Electric Co., Schenectady, N. Y.

Combination Meter-Time Switch.—Cat. Sec. 42-770, 8 pp. Describes types TCS and TCA combination watthour meters and time switches for metering or controlling either two-rate or off-peak domestic loads. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

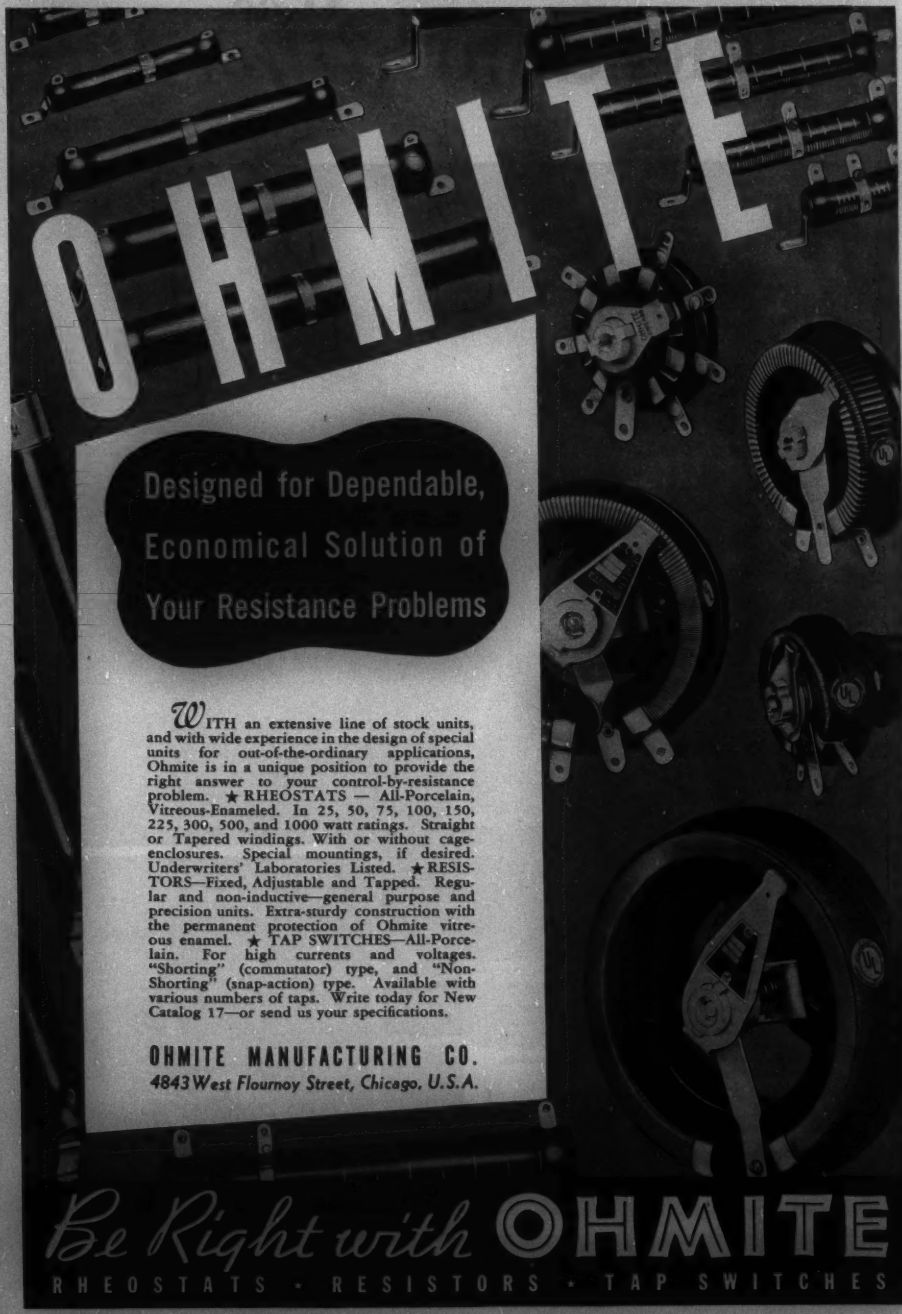
Industrial Lighting.—Booklet, "The Meaning of the RLM Label." Describes the principles of modern industrial lighting and outlines the basic standards of efficiency, design and quality of the various types of lighting reflectors bearing the RLM label. RLM Standards Institute, 20 N. Wacker Drive, Chicago, Ill.

"De-Ion" Power Fuse.—Bulletin F.8450, 8 pp. Describes dry boric-acid power fuses used for the protection of high voltage circuits and equipment, applicable in utility and industrial power plants. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Lighting Equipment.—Bulletin, 24 pp. Described as a new handbook on localized lighting. Outlines the need for supplemental lighting in many production, assembly and inspection operations. Comprises 700 distinct lighting units; models range from small units using 6–8 volt lamps up to 120-inch canopy units using four 150-watt lamps. The majority are flexible arm models. The Fostoria Pressed Steel Corp., Fostoria, Ohio.

Panel Instruments.—Cat. Sec. 43-370, 12 pp. Describes a line of miniature panel instruments covering industrial and radio applications and providing for the measurement of direct current, rectox types, thermocouple types and alternating current. Discusses the two types of mechanisms employed in these instruments, the permanent magnet moving coil type and repulsion vane type. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Thermionic Amplifier.—Catalog E-00A, 8 pp. Describes the thermionic amplifier for voltage measurements in high resistance circuits. This instrument adapts any potentiometer of suitable range for glass electrode measurements and other measurements of potential in high resistance circuits. It is useful in polarization studies, in measurements of corrosion and oxidation-reduction potentials and in the measurement of resistors of high values. Leeds & Northrup Co., 4962 Stenton Ave., Philadelphia, Pa.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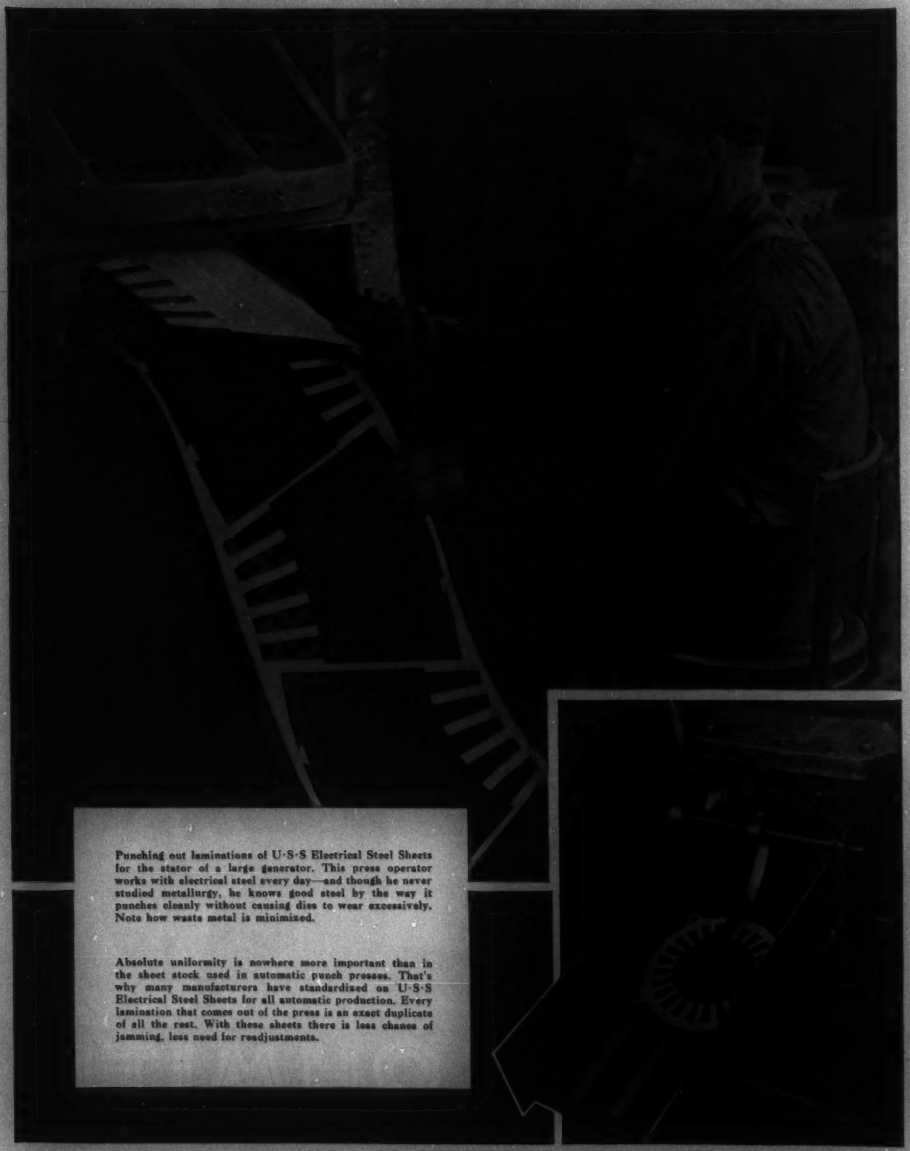

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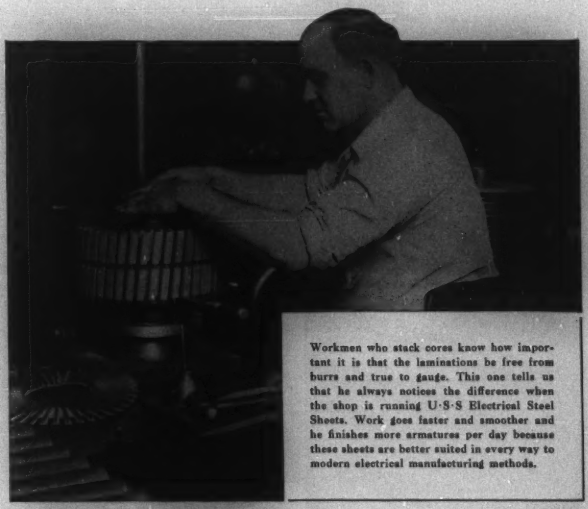

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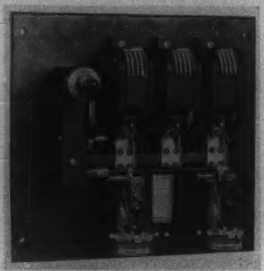
New Products

Air Circuit Breaker.—A new air circuit breaker for the protection of power and lighting circuits with an interrupting rating of 10,000 amperes has been introduced by

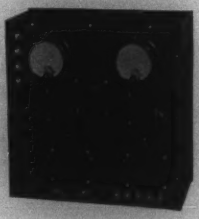


the General Electric Co. Designated type AE-1A, the new device is available in the ratings 600 volts a-c; 250 volts d-c; 15–225 amperes. The breaker, completely enclosed in a steel housing, features a system of arc quenchers and barriers which prevent arcs from occurring between the contacts and the steel enclosing cover. The arcs are extinguished in less than fifteen-thousandths of a second after the contacts part. The AE-1A breaker is offered in single, double, triple and four-pole units, for manual or electrical operation, live- and dead-front switchboard mounting.

Resistors.—Further refinements are featured in the new Pyrohm, Jr. wire-wound, vitreous-enameled resistors, announced by the Aerovox Corporation, 70 Washington St., Brooklyn, N. Y. Special resistance

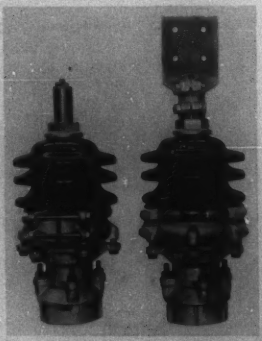
wire of low temperature coefficient of resistivity is wound on refractory tubing. This assembly, including terminal connections, is coated with powdered glassy enamel and fired at red heat. The result is a resistor covered with vitreous enamel tightly fused to the wire, terminal connections and tubing. Proper annealing assures that the resistance wire will not change in service. Connections can be made either to the soldering lugs or to 2-inch bare pigtails. Units are available in 10- and 20-watt sizes, and in an extremely wide range of resistance values.

Impulse Measurement Instrument.—The time during which an a-c circuit is energized is shown directly on a meter scale in a new instrument known as the RayTimeR, introduced by the Raytheon Mfg. Co., 149 Willow St., Waltham, Mass. It may be calibrated in either cycles or seconds and covers with equal precision excitation periods from $^1/_{120}$th of a second to 30 seconds, the accuracy being plus or minus 5 per cent. It is a simple electronic device with no moving parts except the indi-



cating pointer and requires no maintenance other than the occasional replacement of the vacuum tube. The illustration shows a double unit having two RayTimeRs assembled in one container for convenience in measuring two different impulses simultaneously. The RayTimeR has a wide field of usefulness including checking welder and X-Ray exposure timing, measuring the closing and opening time of relays and contactors, measuring time periods and operating speeds of mechanisms having electrically actuated sequences.

Cable Entrance End Seal.—This new type SAO, 2500-ampere, 7.5-kv terminator for 2500-mcm, 2.74-inch O. D. cable, developed by the Delta-Star Electric Co., 2400 Block Fulton St., Chicago, Ill., has a



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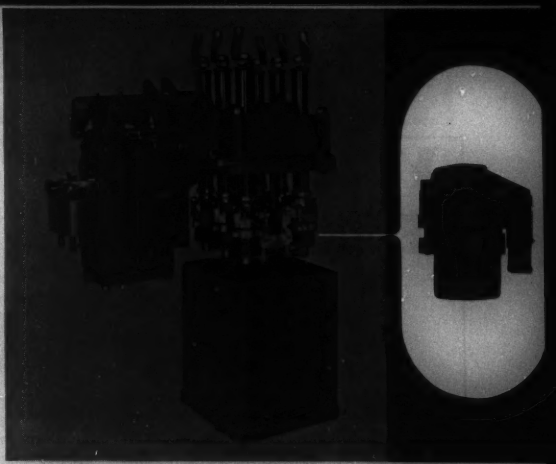

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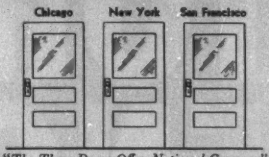

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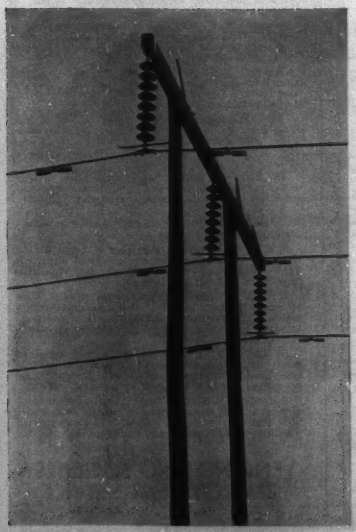

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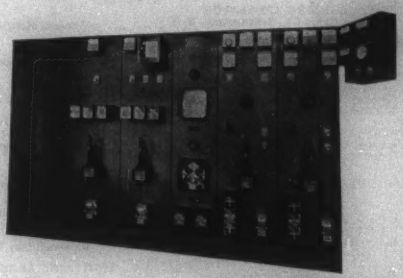

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Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.

SURGE ABSORBERS
Ferranti Electric, Inc., New York

SWITCHBOARDS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.
I-T-E Circuit Breaker Co., Philadelphia
Roller-Smith Co., New York

SWITCHES, AUTOMATIC TIME
General Electric Co., Schenectady, N. Y.
Minerallac Electric Co., Chicago

SWITCHES, DISCONNECT
General Electric Co., Schenectady, N. Y.
Roller-Smith Co., New York

SWITCHES, GENERATOR FIELD
I-T-E Circuit Breaker Co., Philadelphia

TOWERS, TRANSMISSION
American Bridge Co., Pittsburgh

TRANSFORMERS
Acme Elec. & Mfg. Co., Cuba, N. Y.
Allis-Chalmers Mfg. Co., Milwaukee
Ferranti Electric, Inc., New York
General Electric Co., Schenectady, N. Y.
General Radio Co., Cambridge, Mass.

TURBINE GENERATORS
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.

TURBINES
Allis-Chalmers Mfg. Co., Milwaukee
General Electric Co., Schenectady, N. Y.

WATCHES, STOP
Meylan, A. R. & J. E., New York

WELDERS, ARC
General Electric Co., Schenectady, N. Y.

WELDING WIRE
American Steel & Wire Co., Chicago
General Electric Co., Schenectady, N. Y.

WIRES AND CABLES

Aluminum
Aluminum Co. of America, Pittsburgh

Armored Cable
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.

Asbestos Covered
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
General Electric Co., Bridgeport, Conn.
Okonite Company, The, Passaic, N. J.

Bare Copper
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.
Crescent Ins. Wire & Cable Co., Trenton, N. J.

Bronze
Copperweld Steel Co., Glassport, Pa.

Copper Covered Steel
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Copperweld Steel Co., Glassport, Pa.

Flexible Cord
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.

Heavy Duty Cord
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
Okonite Company, The, Passaic, N. J.

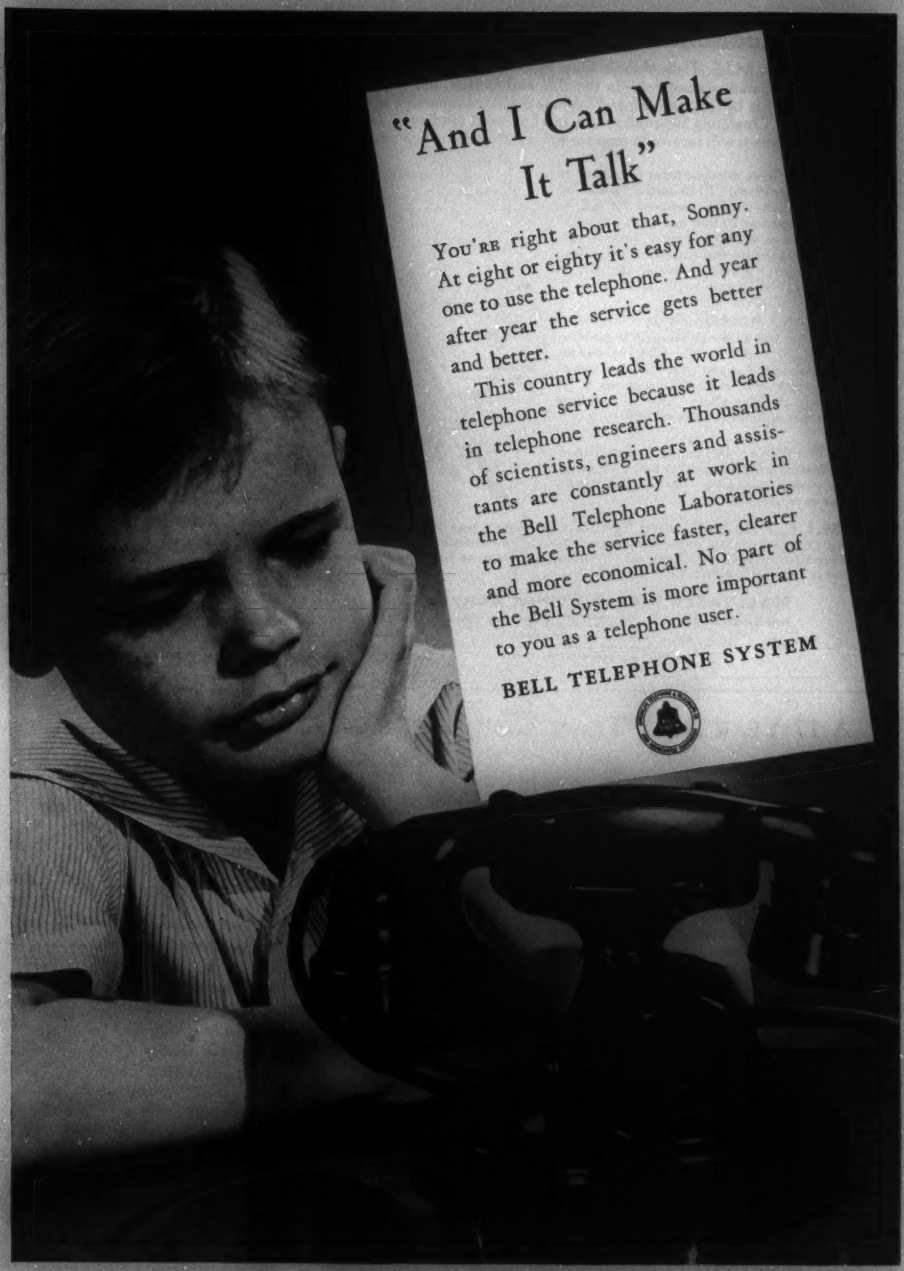
Lead Covered (Paper and Var. Cambric Ins.)
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.
Okonite-Callender Cable Co., Passaic, N. J.

Magnet
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Electric Co., Schenectady, N. Y.

Rubber Insulated
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
General Electric Co., Schenectady, N. Y.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.

Tree Wire
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
Kerite Ins. Wire & Cable Co., New York
Okonite Company, The, Passaic, N. J.

Weatherproof
American Steel & Wire Co., Chicago
Anaconda Wire & Cable Co., New York
Crescent Ins. Wire & Cable Co., Trenton, N. J.
Copperweld Steel Co., Glassport, Pa.
General Electric Co., Schenectady, N. Y.
Okonite Company, The, Passaic, N. J.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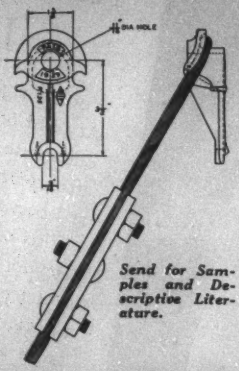

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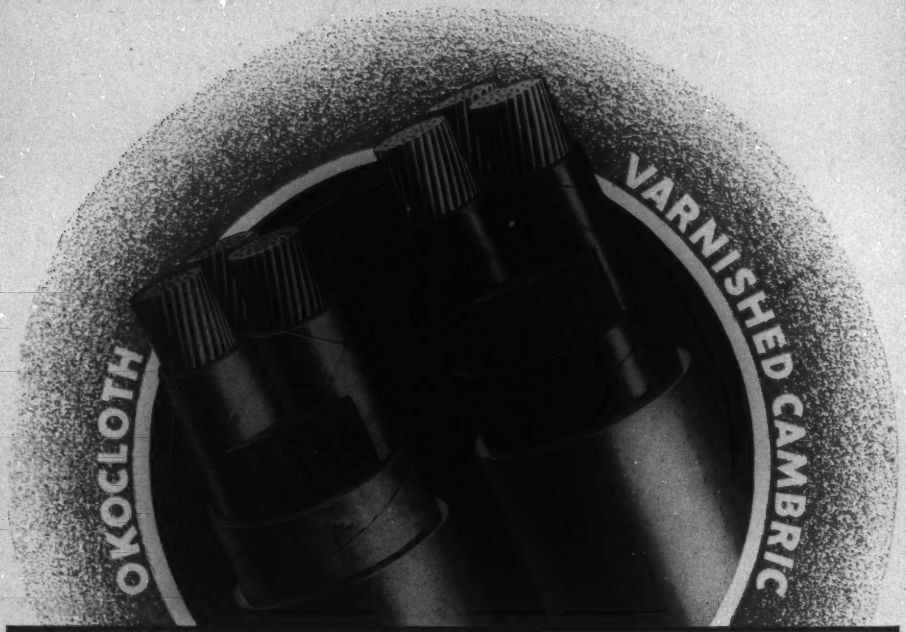

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